EXHIBIT DX3

TO DECLARATION OF PETER GOSS IN SUPPORT OF DEFENDANTS' MOTION TO EXCLUDE THE OPINIONS AND TESTIMONY OF GARY SETTLES, PH.D.

Schlieren Imaging of Operating-Room Airflows Associated with Patient Warming Blankets

Gary S. Settles, PhD.

Distinguished Professor of Mechanical Engineering Emeritus,
Penn State University;
Founder & Director of R&D, FloViz Inc.
76 Sky Harbor Dr., Port Matilda PA 16870
gary@flovizinc.com
(814) 404-5428

June 1, 2017

Qualifications

My name is Gary Stuart Settles. I received the PhD. Degree from Princeton University in 1976, from the Department of Aerospace and Mechanical Sciences. My field of study at Princeton was fluid dynamics, the study of the flow of gases and liquids, and that has also been my lifelong scientific pursuit, especially in fluid-dynamic experiments and the application of optical flow diagnostics.

I joined the faculty of Mechanical Engineering at Penn State University in 1983, where I established a fluid dynamics and optics laboratory. 20 PhD students earned their degrees under my direction at Penn State, along with many Masters degree and undergraduate students. Research topics in my laboratory that are pertinent to the current court case include the human thermal plume, laminar downflow of air in clean rooms, the spread of infection by coughing and sneezing and the effect of wearing a mask, and the schlieren optical technique for imaging thermal airflows. I retired from Penn State University in 2015 with the rank of Distinguished Professor of Mechanical Engineering, Emeritus.

Science Citation Index lists 111 journal publications of which I am author or co-author. My book on *Schlieren and Shadowgraph Techniques* (Springer-Verlag, 2001) has been cited 1,543 times to date, according to Google Scholar.

Following retirement from Penn State I have continued my research activities with FloViz Inc., a Pennsylvania small business, where I currently hold the position of Director of Research & Development.

My professional curriculum vitae is attached at the end of this report

Disclosures

FloViz Inc. was asked on behalf of the 3M Company to apply the schlieren optical technique to visualize the thermal airflows associated with patient warming blankets including the 3M Bair Hugger Model 52200 Upper Body Temperature Management Blanket. Insofar as the optical equipment required to do this could not fit within the confines of a typical hospital Operating Room (OR), an experimental simulation thereof was set up in facilities maintained by FloViz Inc. (to be described fully later in this report). For this experimental program and the production of the present report, FloViz Inc. was paid $70,000. In addition to myself, other Company personnel who worked on this effort were: Lori J. Dreibelbis (Company President) and Larry P. Dreibelbis and James D. Miller (Technicians).

My opinions expressed in this report are based on the experiments carried out on behalf of the 3M Corporation, and on my experience.

My hourly charge for deposition and court appearances is $600. I have given no court testimony in the past four years.

Introduction

Schlieren photography is a scientific imaging technique which reveals phenomena that refract light, even though these phenomena may be invisible to the unaided eye [1]. It is similar to microscopy and telescopy in that precise optics are required, and like these techniques, its introduction dates back several centuries.

The first use of schlieren optics in medicine, however, was apparently in the mid-20th century [2]. Medical doctor H. E. Lewis, while touring a wind tunnel facility at the National Physical Laboratory in England, noticed that thermal convection from the human body was imaged by the same schlieren system that was installed for the observation of high-speed airflows in the wind tunnel. Thus began the practice of using the schlieren technique to investigate the airflow about the human body [3,4], issues of disease spread by coughing and sneezing [5-10], and airflow patterns in industrial cleanrooms and in hospital operating rooms (ORs) designed to maintain particle-free airflow patterns in order to minimize patient infection by airborne pathogens, especially bacteria-bearing human skin flakes or squames [11-13].

Schlieren optics are ideal for these purposes so long as there are temperature differences present in the flow. The schlieren technique passes a beam of light through the airflow under investigation. This schlieren beam is neither a laser nor a powerful spotlight. It is weaker than a flashlight beam and can have no possible effect upon the airflow patterns being studied. This makes schlieren imaging more reliable for revealing true thermal airflow patterns than particle-tracer methods of flow visualization [14], such as smoke, fog, helium-filled micro-bubbles, and particle-image velocimetry (PIV). One reason is that particles in an airstream have inertia and therefore do not always follow the streamlines of the flow. This is especially problematic for helium-filled micro-bubbles [15, 16], the utility of which has been severely limited for decades due to this drawback. Another reason is that the resulting flow visualization depends on where the particles are introduced, e.g. where they are introduced locally so as to emphasize a feature of the flow and ignore a different feature at a different location. Finally the method of introduction of particles into a flow (e.g. by a hose or wand, sometimes hand-held) can interfere with and distort the flowfield under investigation, and they introduce a secondary particle-laden airstream, with its own momentum and direction, into the flowfield under study.

Caution is required in some cases of schlieren imaging because it integrates all the features of a refractive flowfield along its optical path into a single image. If the flow becomes very complicated and three-dimensional, the resulting schlieren image can be difficult or impossible to interpret. Based on my 50 years of experience with the schlieren technique, I believe I have successfully avoided problems of this type in the current investigation.

Goals

The primary goal of this study is to use schlieren imaging to obtain experimental evidence of the airflow patterns and behaviors associated with patient warming blankets in a laminar-downflow operating room scenario. Due mainly to the large footprint of a suitable schlieren optical system for such work, it was not feasible at the outset to conduct these experiments within the limited confines of an actual hospital OR[1]. Instead, the approach taken here is to experimentally reproduce a typical OR laminar downflow, and to use that with a full-sized human mannequin

[1] However, see the later discussion of the feasibility of applying the Background-Oriented Schlieren (BOS) technique in an actual hospital OR.

and actual commercial-product warming blankets, drapes, etc. in order to investigate the airflow patterns of interest.

It is therefore not the current intent to simulate the shape, size, outflow vents, or air changes per hour of an actual OR. Our interest lies solely on the laminar downflow and its interaction with a mannequin on a table simulating a patient undergoing an operation, a patient-warming blanket, OR personnel in close proximity to the simulated operating table, and a simulated overhead surgical lamp. The focus of the investigation is on the interaction of the downflow and the warming blanket, in order to assess the validity of claims that the warming blanket overcomes or materially interferes with the laminar downflow of air over the surgical table.

Materials & Methods

The experimental setup used in this study is diagramed (to scale) in Fig. 1 of the mockup OR surgical table and laminar downflow generator used here for the purpose of schlieren visualizations of the 3M Bair-Hugger patient-warming blanket and a competing warming device, the HotDog. Dashed circles represent several different positions of the 30” schlieren field-of-view (described further below) with respect to the mannequin atop the table. Since the position of the optical field-of-view is difficult to change, the patient and surgical table are elevated or moved to the side in order to explore different regions of the airflow interacting with them. In all cases the schlieren field-of-view remains centered beneath the downflow generator.

As shown in Fig. 1, we image and investigate the airflow from above the Bair-Hugger blanket to its side and then down to the floor in order to address plaintiff claims that the Bair-Hugger exhaust picks up floor contamination and returns it to the surgical site. Since the 30”-diameter schlieren beam is at a fixed location above the laboratory floor, the mockup shown in Fig. 1 (along with its false floor) is elevated and positioned in order to examine the regions shown by the dashed circles.

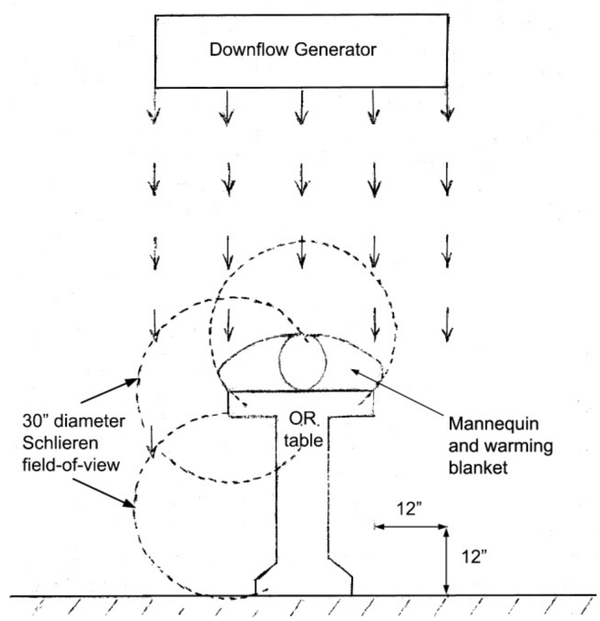


Fig. 1 - Diagram of mockup OR used to visualize airflow about patient and warming blanket.

Schlieren Optical System

The large schlieren optical system that we have used for the work described here has a circular field-of-view of 30 inches diameter. It is based on two large, heavy, precise parabolic telescope mirrors (Fig. 2), and requires a length of about 14 m or 46 feet for its setup, including sufficient space for the experiment in the test area shown. This schlieren system is not portable and does not fit the typical OR dimensions of approximately 25x25 feet. It was set up for the present series of experiments in an open warehouse building of suitable dimensions.

The use of twin parabolic mirrors produces a parallel light beam of 30-inch (0.76 m) diameter, as shown in Fig. 2, which is necessary in order to adequately image the necessary OR field-of-view. Schlieren optical systems of this type are of traditional design as described in Ref. [1], but few such systems this large are to be found outside government research labs.

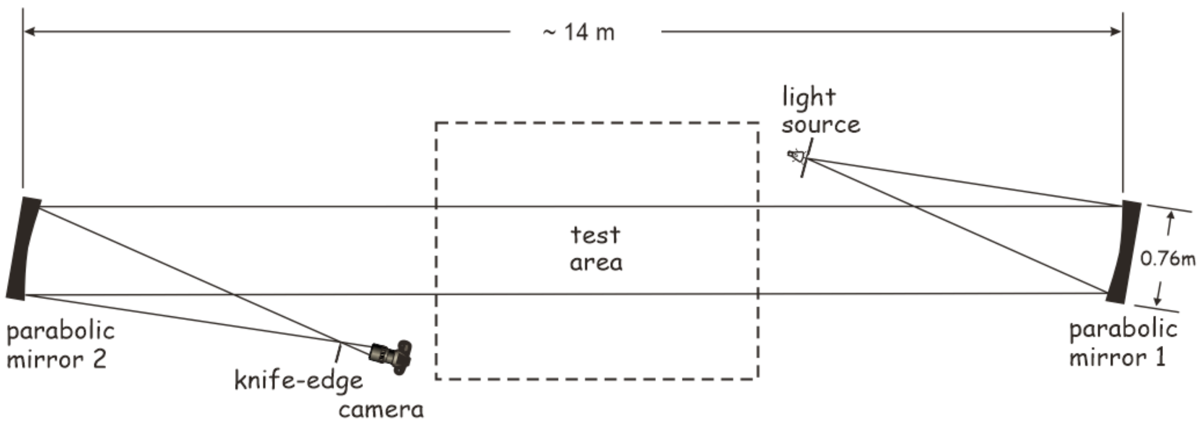


Fig. 2 – Diagram of 30" (0.76 m) parallel-beam schlieren optical system used in the present study.

For one experiment reported below it was necessary to obtain a closeup view of airflow exiting a Bair-Hugger patient warming blanket. For this purpose a small single-mirror [1] schlieren instrument with a 4.25 inch (108 mm) diameter mirror was used. Air temperatures in this experiment were measured using a Sper Scientific 4-channel Thermocouple Thermometer.

All video and still-image schlieren results were captured using a Nikon D90 digital single-lens reflex camera with either a 100 mm or 85 mm fixed-focus lens. This camera produced still images in JPG format with 5.9 to 6.5 megabyte size and HD video clips in AVI format with typical lengths of 10 sec and sizes of 35 megabytes. These results are identified by digital filenames having the prefix "DSC_" followed by a number in the range of 0040-0329. For essentially every setup and airflow configuration tested here, one or more unique still images and a typically-10-sec-long video clip were acquired. Only still images are given as illustrations in this report, but accompanying video clips are identified by filename in the figure captions.

No authentic OR overhead lamp was available for this study, but this equipment was simulated by a photographic floodlamp (Calumet PS4 Power Supply and S2 Standard Lamp Head) having a large dish-shaped reflector (20" Beauty Dish) similar in shape to typical OR overhead lamps. The reflector diameter was chosen based on the 19-inch diameter that was determined from figures presented by Elghobashi [17].

Downflow Generator

A key issue in the technical literature on hospital ventilation is the speed of the downflow in laminar downflow ventilation of the OR. Standards such as those produced by ASHRAE [18] prescribe the number of air changes per hour (ACH) in the OR, which is aimed at controlling the airborne particle count. The speed of the laminar downflow, however, is important to maintain even though it changes with the volume of the OR and the area of the inlet vents for fixed ACH. This is because it is the speed of the downflow that directly counteracts the buoyant rise of thermal currents from people, equipment, patient-warming blankets, etc. If the downflow speed is too low, contaminated air may rise from thermal sources, spread, and reach the surgical site. There is also a concern that, if the downflow speed is too high, it can suppress the natural thermal plume rising from the surgical site and impinge contaminants upon the patient and upon the surgical wound.

There is disagreement in the literature about the OR laminar downflow airspeed. Memarzadeh and Manning [19] used 30-38 feet/minute (fpm) downflow in their CFD simulations, while Sikka and Prielipp [20] state the downflow speed to be in the 60-90 fpm range. Cook and Int-Hout [21], however, argue that 90 fpm is too fast for the OR, and they recommend 30 fpm. Finally an example OR at a hospital in the Minneapolis metropolitan area and the OR airflow parameters assumed by Elghobashi for his CFD simulation [17] are almost identical at 1.1 m^3/sec input airflow rate, 24-27 ACH, and a downflow speed at the ceiling grille outlet of 0.19 m/s or 38 fpm. For consistency we have therefore adopted 38 fpm as the target face velocity of the air exiting our downflow generator in the current study.

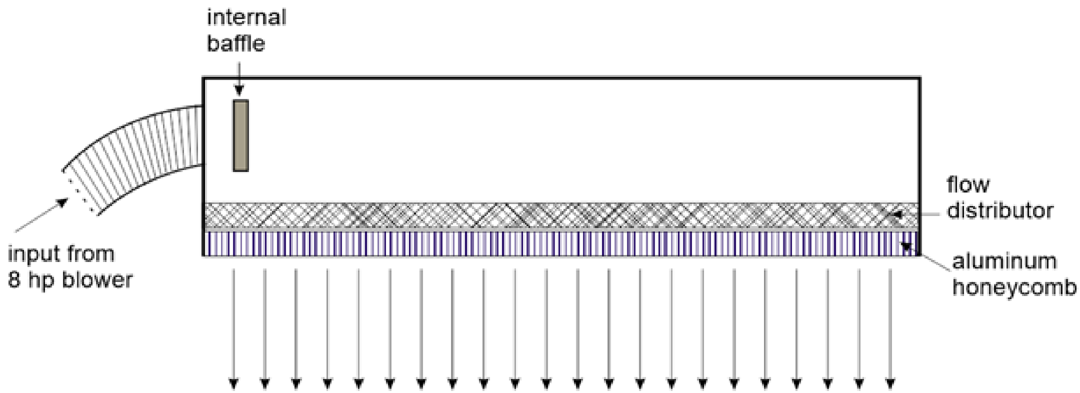


Fig. 3 – Downflow generator diagram

A cross-sectional diagram of the downflow generator developed for the current study is shown in Fig. 3. It consists of a rectangular box of 4x5 feet (1.2x1.5 m) horizontal dimensions and 1.5 feet (0.46 m) high, open on the bottom. It is fed at one side by a hose connected to a throttleable 8 hp blower which is adjusted, in practice, to yield the required downflow speed of 38 fpm on average across the exit of the downflow generator. A TSI Inc. Model 9515 Air Velocity Meter is used to measure this exit downflow speed, or face velocity. Results showed an average of 39 fpm with a standard deviation of 12 fpm.

The device is designed to be a uniform flow distributor by providing several layers of mesh material (intended for use as furnace filters) through which the exiting airflow must pass. A proper flow distributor imposes a sufficient pressure drop upon the airflow that the distance from the blower input and internal baffle becomes irrelevant [22]. An aluminum honeycomb flow

straightener then ensures that the airflow exits the downflow generator headed uniformly in the downward direction.

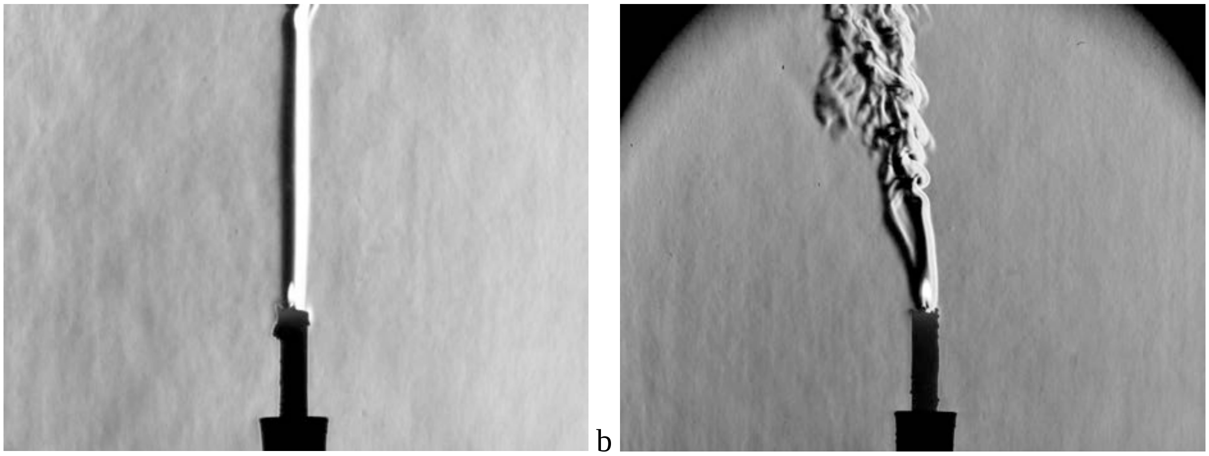
Patient Warming Blankets

For the present experiments where a patient warming blanked was used, it was primarily a 3M Bair Hugger Model 52200 Upper Body Temperature Management Blanket driven by a 3M Bair Hugger 775 Temperature Management Unit. In a few comparison experiments a HotDog Patient Warming REF B103 blanket was used, powered by a HotDog WC51 Unit.

Results and Discussion

Demonstration Images and Videos

Because schlieren photography is unfamiliar to most lay people, the 30” schlieren system was first used to image the thermal airflows about familiar objects for demonstration purposes. Figs. 4a and 4b are schlieren images of an ordinary candle flame and its thermal plume without and with the 38 fpm downflow described above, respectively. A lit candle is a very hot thermal source that produces a strongly-buoyant laminar plume in undisturbed air. This plume is seen to begin undergoing natural transition to turbulence at the top of the frame in Fig. 4a. The downflow is unable to suppress this strong plume but does disturb it, leading to early transition to turbulence as shown in Fig. 4b. Note that the down-flowing air is difficult to discern in still schlieren images, but it shows up clearly in the accompanying videos (see video DSC_0250).

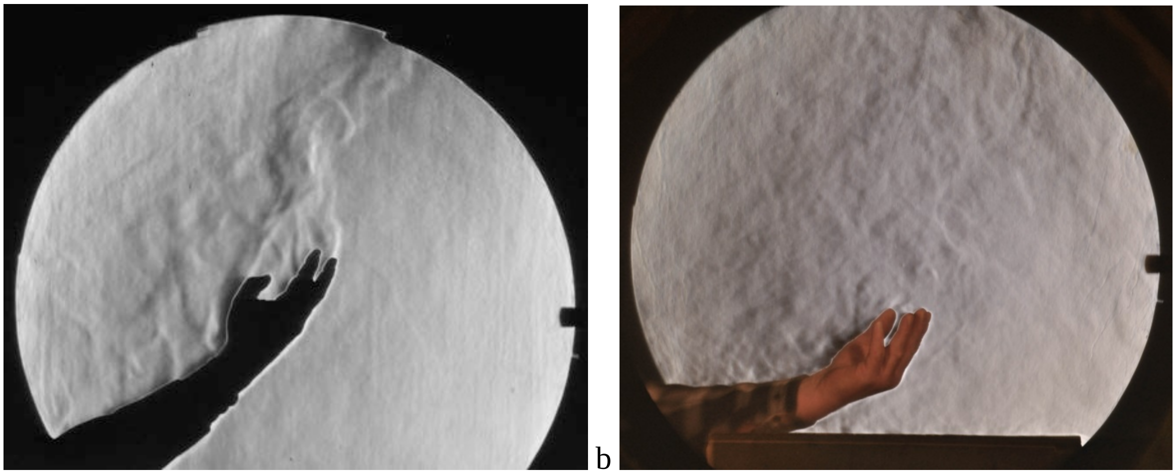


a b

Fig. 4 - Schlieren images of the thermal plume from a lit candle a) without and b) with the 38 fpm downflow from the downflow generator. Corresponding videos are DSC_0107 and DSC_0051, respectively.

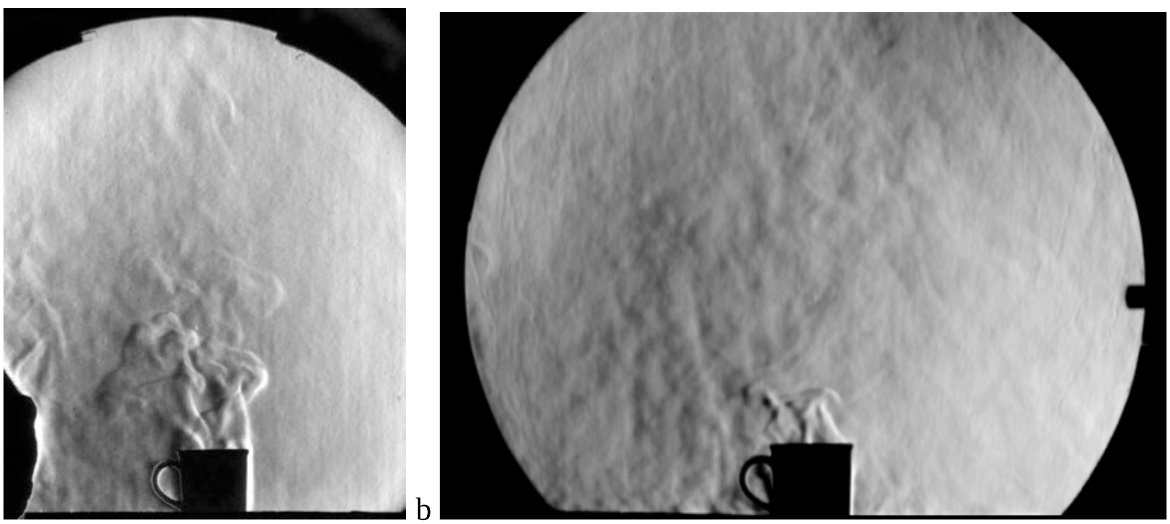
A much weaker disturbance is created by the thermal convection of the human hand, which is typically only a few degrees C above room temperature. Figs. 5a and 5b are schlieren images of a human hand and its thermal plume without and with downflow, respectively. Unlike the case of the candle flame, the weaker plume of the hand is fully suppressed by the 38 fpm downflow.

Similar results are seen from a cup of hot coffee in Fig. 6. Though hotter than the human hand, the coffee’s weak thermal plume is also suppressed by the downflow.



a b

Fig. 5 - Schlieren images of the thermal plume from a human hand a) without and b) with the 38 fpm downflow from the downflow generator. Corresponding videos are DSC_0109 and DSC_0256, respectively.



a b

Fig. 6 - Schlieren images of the thermal plume from a cup of hot coffee a) without and b) with the 38 fpm downflow from the downflow generator. Corresponding videos are DSC_0044 and DSC_0257, respectively.

In Fig. 7a, an ordinary blow-dryer is shown discharging a jet[2] of heated air as observed by the schlieren optics. The camera exposure of ½ millisecond captures the high turbulence level of this jet. It is well known in the field of fluid dynamics that such a coherent turbulent jet can project itself over large distances, many times the initial jet diameter, because of its high momentum and relatively-small spreading rate. In the OR environment, such a jet could be very disruptive. Equipment that could produce such a jet is generally not found in ORs.

Fig. 7b shows a similar but much weaker and less-concentrated turbulent jet produced by the open end of the hose from the 3M Bair Hugger 775 Temperature Management Unit (*without* a Bair Hugger Temperature Management Blanket attached). It is important to note that a strong warning is printed on the end of the hose shown in Fig. 7b, that it is never to be used for patient warming without a Bair Hugger Temperature Management Blanket attached.

---

[2] In fluid-dynamic terms a jet is a fluid stream that emanates from a nozzle and conveys fluid mass and momentum in a specific direction.

In Fig. 7 a blanketed mannequin is also shown atop the surgical table. This will be described in the discussion of later experiments and does not have an active role in the Fig. 7 demonstration of the appearance of turbulent jets under schlieren observation.

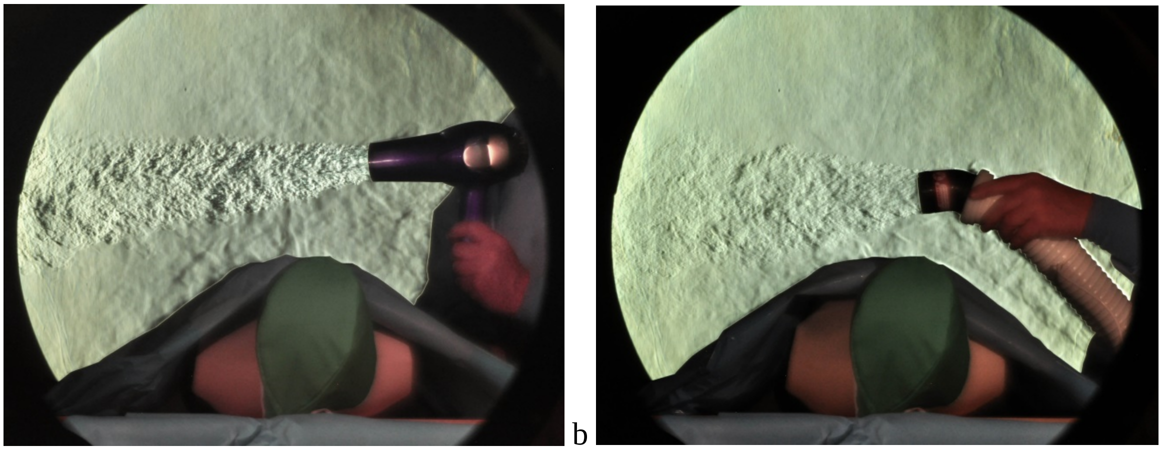
a b


Fig. 7 – a) an ordinary blow-dryer is shown discharging a strong jet of heated air, b) a similar but much weaker and less-concentrated turbulent jet produced by the open end of the hose from the 3M Bair Hugger 775 Temperature Management Unit without a Bair Hugger Temperature Management Blanket attached (instructions clearly forbid the use of this equipment for patient warming in this manner). Imagery obtained with downflow generator in operation. Corresponding videos are DSC_0178 and DSC_0176, respectively.

Convection Currents Generated by Forced-Air Patient Warming

Claims have been made in advertising and in the technical literature [16] that "forced-air warming generate(s) convection currents that mobilise floor air into the surgical site area," thus leading to contamination and increased risk of infection. It is important to explore, using schlieren imaging and ancillary temperature measurements, whether or not such claims actually describe the forced-air patient warming provided by the 3M Bair Hugger Model 52200 Upper Body Temperature Management Blanket when properly used per its provided operating instructions.

The 3M Bair Hugger Model 52200 Blanket is designed to warm a patient undergoing hip or knee surgery. It is an inflatable blanket driven by the airstream that is supplied through a hose by the 3M Bair Hugger 775 Temperature Management Unit. Once the hose is properly attached to the inflatable blanket, there is no longer a possibility of generating a jet of heated air as observed in Fig. 7b. Instead, the forced air exits the blanket through hundreds of micro-orifices distributed over an area of approximately 1 m^2. An image of one of these micro-orifices is shown in Fig. 8a, revealing that it is approximately 0.04" or 1 mm in effective diameter. Thus, instead of by the single large jet shown in Fig. 7b, the heated air exits the Bair Hugger Model 52200 Blanket via hundreds of individual micro-jets.

In order to examine the resulting flowfield, we obtained the close-up schlieren view of these micro-jets shown in Fig. 8b. The Bair Hugger Model 52200 Blanket is at the bottom of this image, and micro-jets of warm air emanating from it are directed upward. These micro-jets are seen to be laminar for a distance of about 1 cm, whereupon they undergo transition to turbulent flow and mix out rapidly with the surrounding air. The total length of the region from the blanket surface to the end of visible mixing with the atmosphere is observed to be about 3 cm in Fig. 8b. This measurement is important because it refutes the claim [16] that "forced-air warming

generate(s) convection currents that mobilise floor air into the surgical site area." The distance from the Bair-Hugger blanket to the floor in our OR mockup is greater than 1 m (39.4 in.).

a b

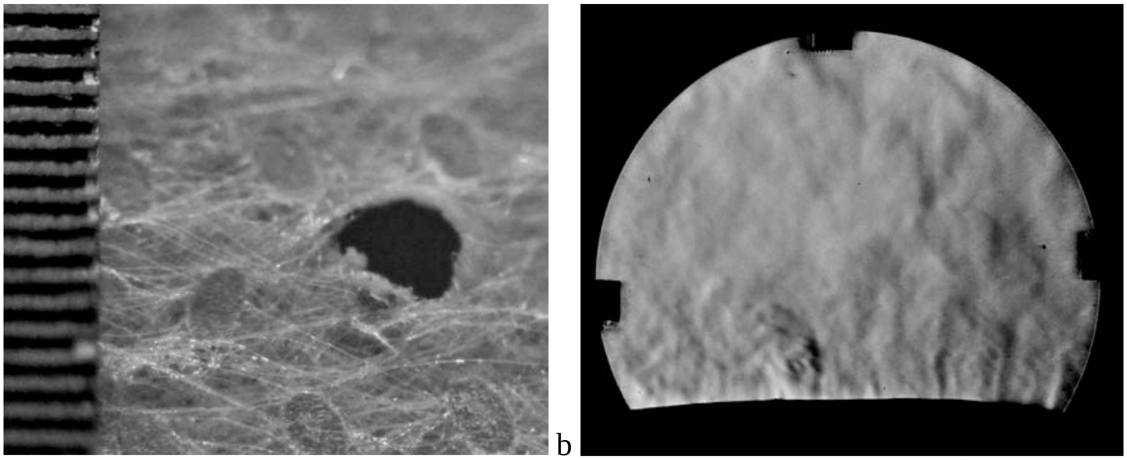


Fig. 8 – a) photograph of a single micro-orifice in the 3M Bair Hugger Model 52200 Upper Body Temperature Management Blanket. Scale at left is graduated every 0.01 inch, b) close-up schlieren image of air exhausting from Bair Hugger Blanket micro-orifices. Corresponding video is DSC_0210. The diameter of the field-of-view in this image is 3.7 in. or 9.4 cm.

To further address this issue, detailed temperature measurements were made directly above a micro-orifice of the Bair Hugger Model 52200 Blanket using a miniature thermocouple probe and a Sper Scientific 4-channel Thermocouple Thermometer. The results of these measurements are shown in a graph in Fig. 9. For this and in Fig. 8b the 3M Bair Hugger 775 Temperature Management Unit was set to 43°C output temperature and its high fan setting.

With the thermocouple directly above the micro-orifice at a distance of 1 mm or less, the exit air temperature was measured to be 32 to 33 degrees C. With increasing distance above the micro-orifice, this temperature drops rapidly due to mixing with the surrounding air, which was at an ambient temperature of 22°C. At all distances greater than 40 mm (1.6 in.) the exit air temperature of the Bair Hugger Model 52200 Blanket was found to be within 1°C of the ambient room temperature.

Of course, in actual use to warm a patient the Bair Hugger Blanket will be placed against the patient's body. Due to the pillowed design of the blanket, some micro-orifices will be blocked, and warm air might accumulate locally before finding its way to the surroundings. Nevertheless our discovery shown in Figs. 8 and 9 is that the length scale of the micro-jet exhaust of warm air from the blanket is on the order of a few centimeters, not the one meter or more that would be required to actively scour bacteria from the OR floor as suggested in [16]. Moreover, even if the Bair Hugger blanket exhaust could reach the OR floor, it would, over that distance, be almost completely mixed out with the surrounding air. It would thus have almost no residual buoyancy with which to rise to a height of perhaps 2 m in order to release bacteria into the surgical site, let alone to buck the 38 fpm downflow of clean air that opposes any such motion.

A further observation can be made: The Bair-Hugger forced-air warming blanket and a competitor's blanket using thermal conduction and warm-air diffusion but no forced-air delivery must both provide a certain thermal power level, for example in Watts, in order to maintain the patient's body temperature at a desired level during surgery. Except at length scales within a few cm from the blanket, as demonstrated above, any excess thermal energy not supplied to the

patient will tend to be shed as a slowly-rising natural convection column above the blanket regardless of whether the mode of operation of the blanket uses or does not use forced air. The ability of such natural convection to move against the downflow of cooler air will be addressed below, but claims of "convection currents that mobilise floor air into the surgical site area" [16] are not supported by any evidence that we have seen in this study.

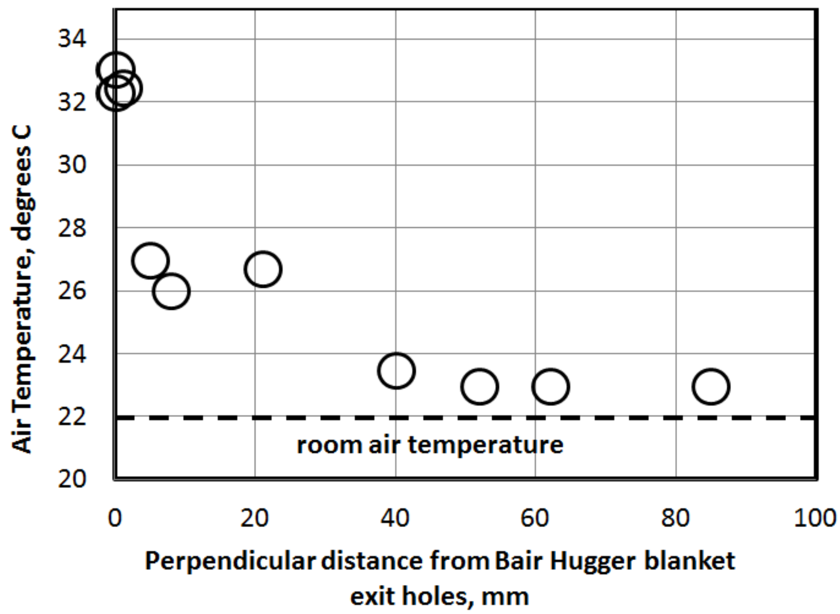


Fig. 9 – Graph showing thermocouple temperature data of air exiting from a micro-jet orifice of a 3M Bair Hugger Model 52200 Upper Body Temperature Management Blanket. The 3M Bair Hugger 775 Temperature Management Unit was set to 43°C output temperature and its high fan setting.

Warming-Blanket Flow and Temperature Patterns in the Simulated OR

In Fig. 10a our mannequin has been arranged with its arms spread on an arm-board and its upper body covered with a Bair Hugger Model 52200 Blanket and a cotton blanket. A lower-body drape has also been added per standard OR procedure. The Bair Hugger 775 Temperature Management Unit was set to 43°C output temperature and its high fan setting, and the downflow generator is operating with its standard average face velocity of 38 fpm. Thermal convection is seen to rise from the blanket, but it struggles to buck the downflow and generally fails to do so.

In Fig. 10b the mannequin is covered by a HotDog Patient Warming REF B103 blanket powered by a HotDog WC51 Unit set at 43°C (both settings). Downflow conditions were the same. As in Fig. 11a, thermal convection is seen to rise from the blanket, but it too fails to buck the downflow.

There are no great differences in the visible thermal behavior of the Bair Hugger and the HotDog patient warming blankets in Fig. 10, the latter of which does not use forced air. In neither case are convection currents seen that do not arise directly from the respective warming blankets. Certainly no convection currents are observed rising from the floor and reaching the surgical region on the mannequin.

Memarzadeh and Manning [19] believe that the thermal plume rising from the surgical wound protects it from particles other than those due to the patient, so long as the laminar downflow speed is not so fast that it overcomes that plume. This philosophy is also expounded in an

ASHRAE manual [23] that deals with OR ventilation design. To the extent that this is correct, patient warming blankets including the 3M Bair Hugger products should have a positive rather than negative effect on the rate of surgical site infection, since they add warm air to the naturally-rising thermal plume of the patient without disrupting the downflow, as shown in our investigation.

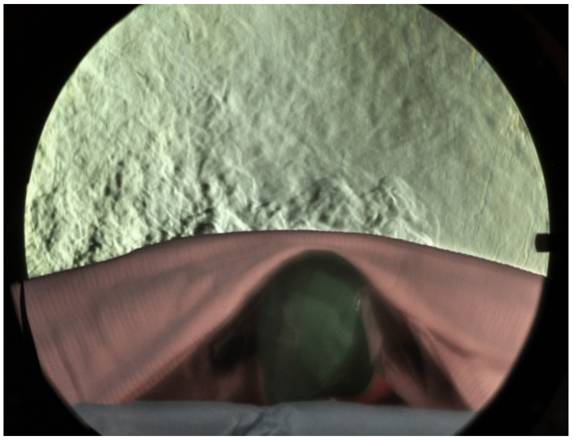
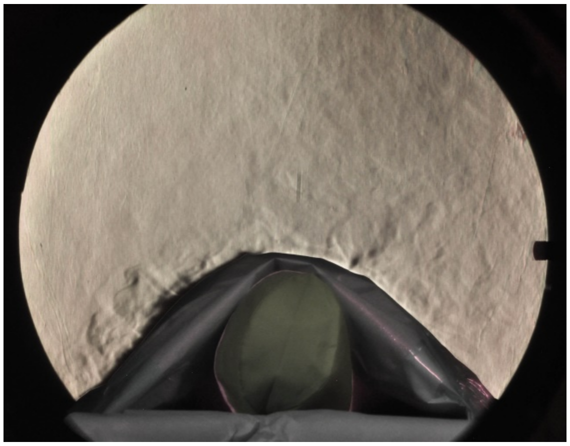
a  b 

Fig. 10 – Schlieren images of a) Bair Hugger 52200 and b) HotDog REF B103 patient blankets on mannequin with downflow (see text for details). Corresponding videos are DSC_0171 and DSC_0181, respectively.

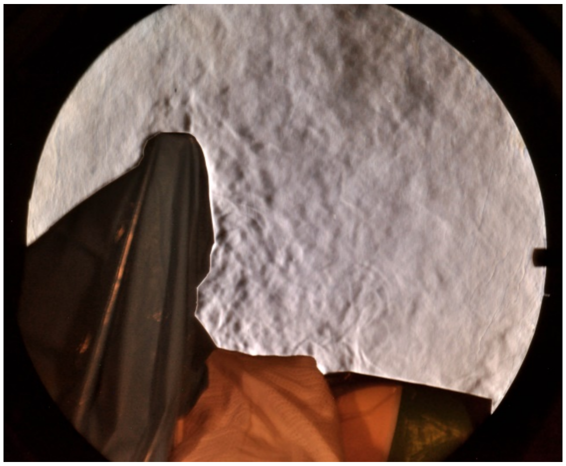


Fig. 11 – Anesthesia curtain at left, mannequin's head at lower right, side view. The downflow was on and the Bair Hugger 52200 blanket was in use (43°C and high fan speed). Corresponding video is DSC_0280.

The anesthesia curtain normally used during surgery has been omitted thus far because it blocks the schlieren beam in views along the length of the patient's body. In order to include it we have rotated the surgical table in order to get a side view, Fig. 11b. Some thermal convection from the Bair Hugger blanket is seen to collect underneath the tent formed by the curtain and spill out, where it then interacts with the downflow and is directed out and away from the surgical site.

Because of the drapes, anesthesia curtain, etc., some locations were not optically accessible to schlieren observation. It was decided to probe these locations using the TSI Inc. Model 9515 Air Velocity Meter in thermometer mode. This meter has a long, thin wand probe which helps to reach inaccessible locations without undue interference. For these measurements

the mannequin was arranged with its arms spread on the arm-board and its upper body covered with a Bair Hugger Model 52200 Blanket and a cotton blanket. A drape was also used to cover the torso and legs. The Bair Hugger 775 Temperature Management Unit was set to 43°C output temperature and its high fan setting, and the downflow generator was operating. The ambient room temperature was 17°C (63°F). The diagrams shown in Figs. 12 and 13 illustrate this configuration, the locations of the temperature measurements, and the temperatures measured there.

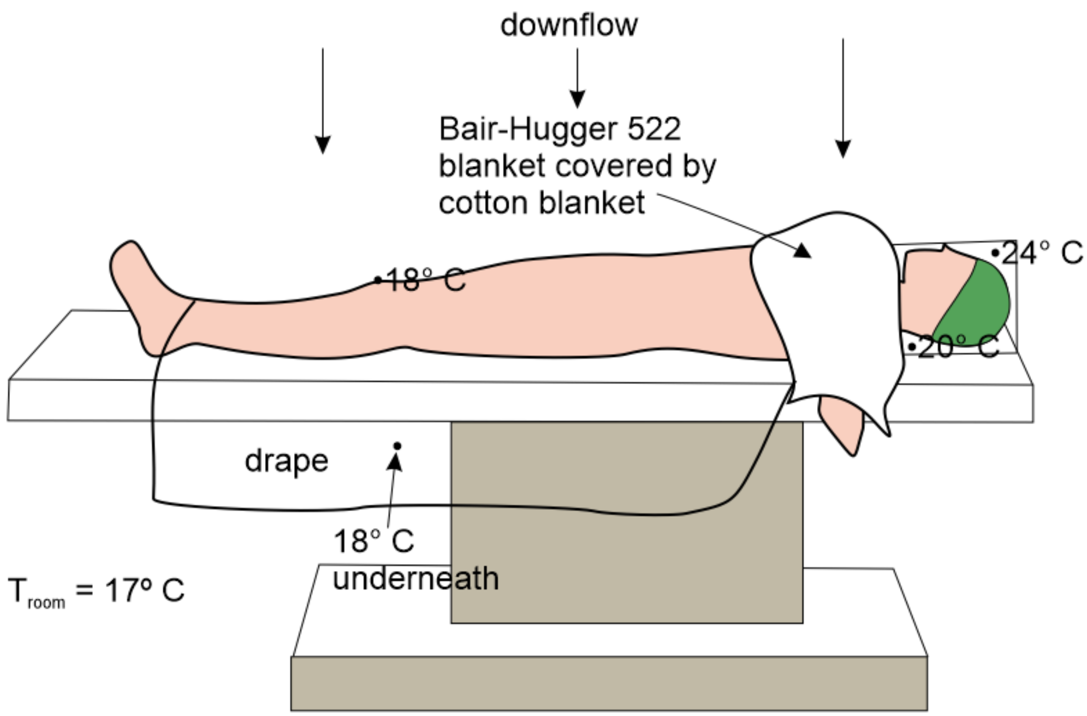


Fig. 12 – Diagram showing temperatures measured in locations inaccessible to schlieren observation (side view). See text for details.

The measurements shown in Figs. 12 and 13 reveal that, even though the Bair Hugger 775 Temperature Management Unit was set to 43°C output, the highest temperature measured underneath the blanket and drape is only 28°C. This disproves the flawed concept of hot convection currents underneath the blanket and drapes reaching the floor and stirring up contamination there [16], and also provides a proper temperature boundary condition for air beneath the drapes, to which we will return in a later discussion of the CFD results of Elghobashi [17].

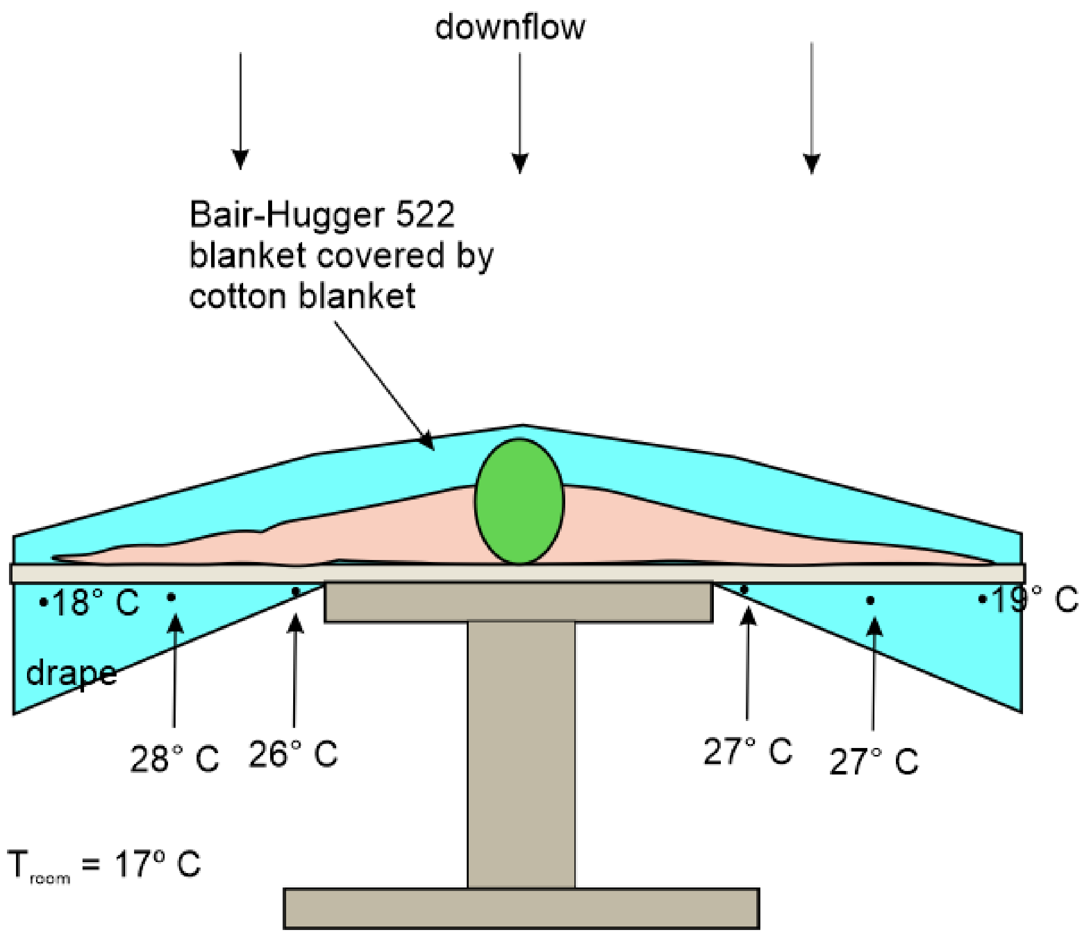


Fig. 13 – Diagram showing temperatures measured in locations inaccessible to schlieren observation (front view). See text for details.

Other OR Thermal Contamination Sources

To place in perspective the thermal characteristics of patient warming blankets, we have also used schlieren optics to examine some other prominent sources of thermal plumes and causes of laminar downflow blockage in the OR.

Power Units of Bair Hugger and HotDog Patient Warming Blankets. In Figs. 14a-d are shown schlieren images of the thermal convection patterns generated by the 3M Bair Hugger 775 Temperature Management Unit and the HotDog WC51 Power Unit. These power units were elevated to reveal the airflow underneath them.

In summary, both power units release heat into the OR environment that is clearly visible in Fig. 14. Both also generate airflows that are visible underneath, although only the Bair Hugger 775 unit filters this air and conveys it by a hose to its warming blanket. Otherwise the differences in these two power units that are visible to schlieren optics are unremarkable.

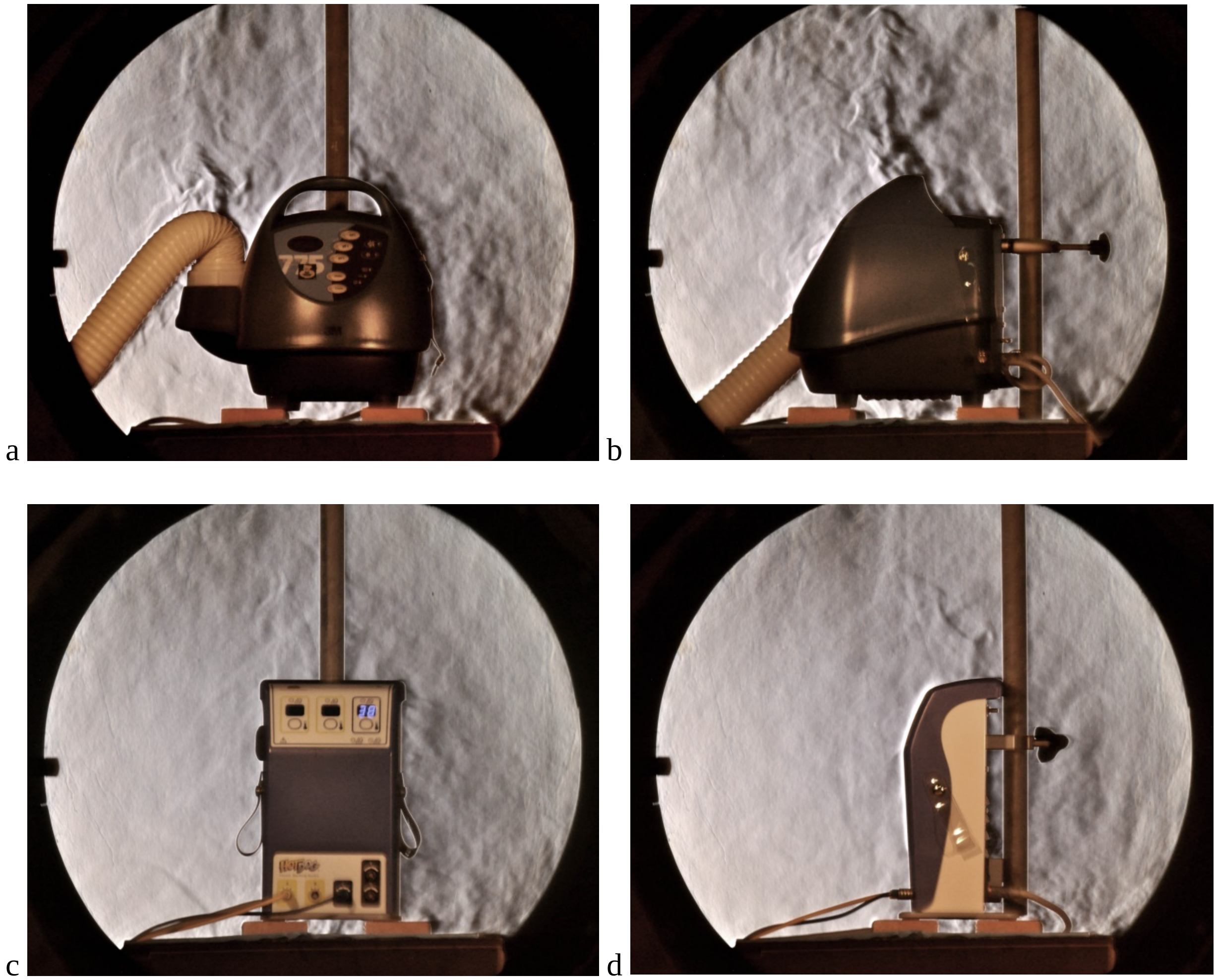


Fig. 14 - Schlieren images of the thermal convection patterns generated by a,b) the 3M Bair Hugger 775 Temperature Management Unit and c,d) the HotDog WC51 Power Unit. Downflow was operational when these images were taken. Corresponding videos for the Bair Hugger and HotDog units are DSC_0239 and DSC_0242, respectively.

Thermal plumes of OR personnel and Equipment It is well known that the human body produces heat in the range of 80 W or higher, depending upon activity level, and that much of this heat is shed in a thermal plume that also contains skin flakes (squames) that can carry a variety of viable bacteria [2-6, 12, 13, 24]. Insofar as surgeons, nurses and other OR personnel stand by the surgical table and move about within the laminar downflow, the visible behavior of their thermal plumes, compared to that of the warming blankets considered above, is worth observing by schlieren imaging.

The weak thermal plume from the human hand has already been discussed (Fig. 5). Fig. 15 shows additional still images and cites corresponding video clips of a human subject in OR garb working within the schlieren field-of-view. In Fig. 15a, the OR staff member simulates working at the surgical site of a patient represented by a mannequin being warmed by a HotDog REF B103 blanket. The thermal boundary layer on the staff member’s chest and face rises due to buoyancy but separates from his head and is driven back to the surgical site by the laminar downflow. This generates a recirculation region bounded by the staff member’s hands, chest, and

face. Such a recirculation region will likely contain many squames shed by the staff member, and has a high potential to deposit them in the surgical wound site. Thus Fig. 15a reveals a more direct mode of possible wound contamination than any airflow pattern generated by warming blankets alone.

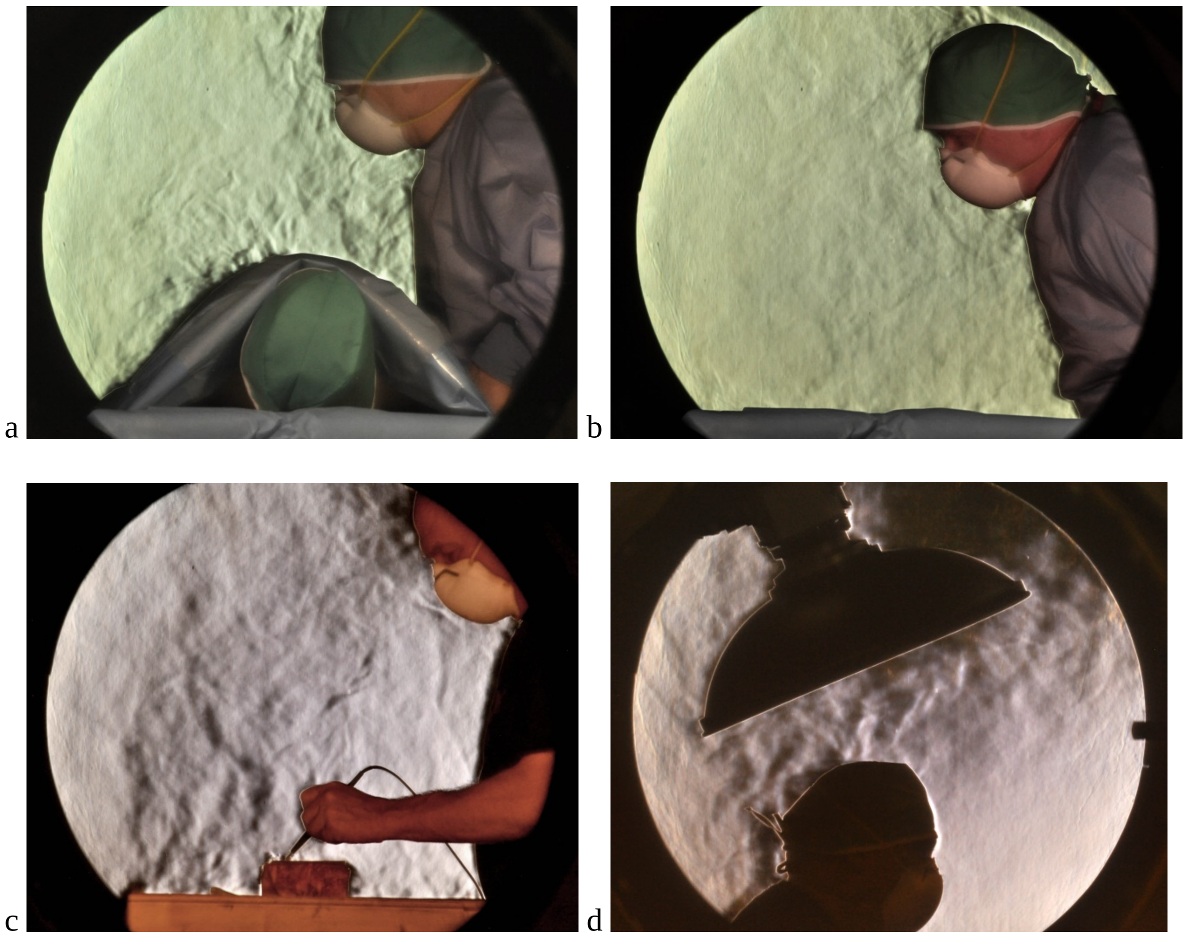


Fig. 15 – Schlieren images of an OR staff member a) working at the "surgical wound site" of a mannequin being warmed by a HotDog REF B103 blanket, b) breathing, which pumps non-sterile air from inside the clothing at the neck, c) using an electrocautery device, and d) underneath a simulated surgical lamp. Laminar downflow was enabled for each of these images. Corresponding videos are a) DSC_0183, b) DSC_0195, c) DSC_0272, and d) DSC_0311.

Fig. 15b shows the same OR staff member above the empty surgical table, and reveals how contamination gets into the recirculation region despite the fact that the staff member is properly gowned. The bright region at his throat is air being ejected from inside his clothing due to the breathing motion of his chest (shown most clearly in accompanying video clip DSC_0195). Air thus injected into the airflow above a surgical wound site would almost certainly contain squames from the staff member, a fraction of which would be bacteria-bearing, per the cited literature.

In Fig. 15c the OR staff member is using an electrocautery device that produces a plume containing cells and combustion products from burned tissue. In Fig. 15d the gowned staff member is standing beneath a simulated OR lamp, whose large diameter creates a "dead zone" in

the laminar downflow. The staff member's thermal plume rises directly into the lamp and recirculates there, well above the surgical wound site, potentially dropping squames into it from the staff member's thermal plume. This is another direct mode of possible wound contamination that does not require an assumed convective flow from a warming blanket to the floor and back up to the height of the surgical lamp shown in the figure.

Background-Oriented Schlieren

The schlieren equipment used here and diagramed in Fig. 2 is much too large to fit into the typical 25x25-foot hospital OR. Therefore, as part of the current effort we evaluated whether a new schlieren technique, Background-Oriented Schlieren or BOS, might be used in an actual OR. BOS requires only simple equipment, replacing precise parabolic mirrors with intense computer image post-processing.

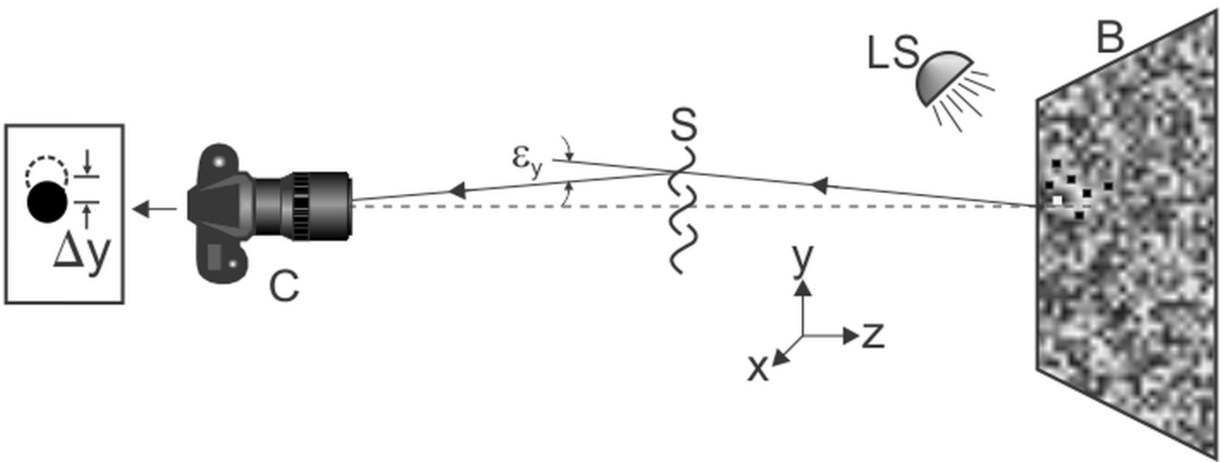


Fig. 16 – Diagram of a BOS setup with patterned background B and digital camera C.. See text for description of other notation.

As diagramed in Fig. 16, the image of a spot on a patterned background B, seen along the dashed straight line without the schlieren disturbance S in place, is shifted (solid line) by the refraction of S. This shift is seen, by way of the small refraction angle ε_y, as a displacement Δy of the spot on the high-resolution digital camera image sensor. Δy can be measured by comparing background images with and without S using digital image cross-correlation software that detects the shift within a small interrogation window. Once Δy is known, the refraction angle ε_y is quickly found from the trigonometry of the setup. But since ε_y is the same quantity measured by a mirror-type schlieren instrument, the results of the digital image correlation can be displayed as a pseudo-schlieren image.

For possible use in an OR, the distances C-to-S and S-to-B in Fig. 16 must both be about 12 feet or 3.7 m, where S is the center of the operating table. Normally, for sharply-focused BOS images, C-to-S should be several times as large as S-to-B. Nevertheless we tried to image the thermal plume of a human hand using BOS with these distances, and obtained the result shown in Fig. 17.

This establishes that BOS can, in principle, be used to image airflows in an actual hospital OR. We reserve the right to conduct a BOS visualization in a hospital OR for use at trial.

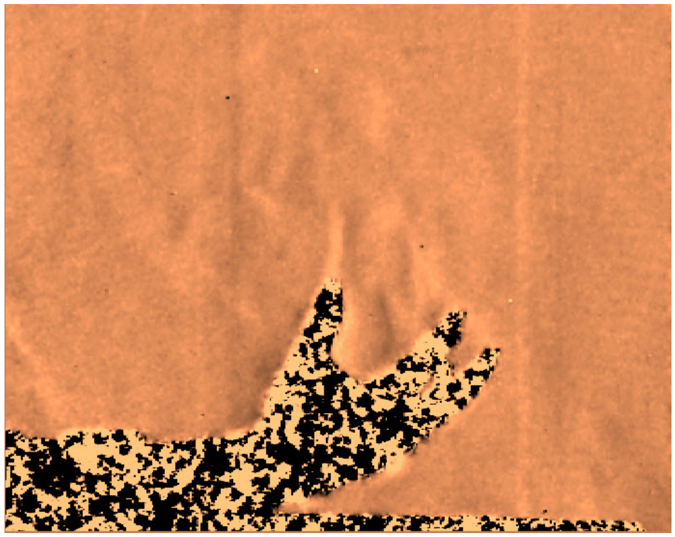


Fig. 17 – BOS image of thermal plume from hand, obtained with distances C-to-S and S-to-B both equal to 12 feet. The blotchy appearance of the hand in this image is typical of BOS computer processing results for solid objects.

Critiques of Plaintiff's Expert Reports

Critique of Expert Report by Said Elghobashi

The expert report by Said Elghobashi [17] presents a very elaborate CFD solution of a simulated OR with staff, overhead lights, side tables, and a patient fitted with a forced-air warming blanket (explicitly called out in Prof. Elghobashi's report as the 3M Bair Hugger Model 522) on a surgical table. The CFD solution uses Large-Eddy Simulation (LES) to represent turbulent air motion, and also calculates the trajectories of 10-micron spheres that are entrained in the flow.

Despite the elaborate nature and obvious cost of this simulation, I believe that it has drawbacks, limitations, and at least one outright failure that compromise its ability to represent the actual airflow produced by a forced-air warming blanket in a real OR environment:

1) There is no validation experiment. The CFD simulation of turbulent flows without any experimental validation is automatically suspect in the fluid dynamics community, and is generally not considered publishable until at least some comparative experimental data becomes available [25].
2) Only a single OR setup is simulated. There are no changes of location of surgical staff, equipment, etc. In fact, only two CFD solutions are discussed, one with the forced-air warming blanket inoperative, and the second with Prof. Elghobashi's representation of the outflow from the 3M Bair Hugger Model 522 blanket in effect.
3) Theoretical 10-micron squame particles are released at the floor of the OR as a "worst case," but it is not a worst case. If squames had been released atop the heads of the simulated medical staff, for example, I believe the computation would have shown them rising to the overhead lamps and then falling with the downflow to the surgical site *regardless* of whether the blower of the patient warming blanket was on or off.
4) My most serious criticism of Prof. Elghobashi's CFD simulation is that he has made a critical mistake in Sec. 3.4.2 of his report, in assuming that the discharge air from the Bair Hugger blanket leaves the lower drape edges at 41°C (106°F), only slightly below the assumed Bair Hugger inlet temperature of 43°C (109°F). As shown earlier in the present report (Fig. 9), the

measured exit temperature of the hundreds of micro-jets from the 3M Bair Hugger Model 52200 Blanket is only 32-33°C (90°F), and the emerging air at that temperature mixes out in a short distance to essentially room temperature. If Prof. Elghobashi had actually modeled the Bair Hugger Blanket in his CFD simulation, he should have observed this rapid temperature drop in the air discharged by the Bair Hugger blanket, which certainly would not have led to the gross convection plume that he observed in his results. But even though his entire CFD simulation was done in order to model the effects of the 3M Bair Hugger Model 52200 Blanket on purported contamination spread in the OR, he incredibly did not execute a computer model of that Blanket at all, but rather simply applied an incorrectly-assumed air discharge condition for which he references a 3M YouTube video [27] describing a different computational study by Prof. John P. Abraham. In that video, the air emerging from the Bair Hugger blanket is assumed to be at 41°C, a conservative estimated in the absence of experimental data at the time. But Prof. Elghobashi has claimed on page 32 of his report [17] that the 3M video [27] states 41°C as the air temperature leaving the drape edge, i.e. in close proximity to the floor of the OR. In fact the video [27] makes no such claim, and we have shown in the present report that the 3M Bair Hugger Model 52200 Blanket is incapable of producing such a high temperature in the immediate vicinity of its air discharge, let alone at a distance of approximately 1 m to the bottom edges of the surgical drapes. I believe that this error in assumed boundary conditions, along with his failure to computationally model the Bair Hugger Blanket itself, completely invalidates Prof. Elghobashi's stated conclusions.

Critique of Expert Report by Dan Koenigshofer

The expert report by Dan Koenigshofer [26] cites his experience with heating, ventilation, and air conditioning (HVAC) and provides a tutorial on hospital ventilation. Much of the text of this report conveys general information not specific to the question of forced-air vs. conduction-type patient warming blankets, though he does provide a brief literature review on this topic. Mr. Koenigshofer has not done any original experiment or computation on the subject, but rather states his opinions "based on physics and clear statements of fact." My responses to his Summary of Opinions are as follows:

1) "The Bair Hugger operating in an OR will create turbulence at the floor, stirring settled particles." It is not clear if he means turbulence created by the power unit sitting on the floor, or by air exhausted from the warming blanket impinging on the floor. In this report I have disproved the latter premise. As for the former, the 3M Bair Hugger 775 Temperature Management Unit does not have to sit on the floor, but can sit on a table or be clamped to a pole instead. Moreover, Koenigshofer has not shown any such disturbance of settled particles at the floor level.
2) "The Bair Hugger draws in particles off the floor into the unit. It functions much like a household vacuum cleaner," Once again the 3M Bair Hugger 775 Temperature Management Unit does not have to sit on the floor, but if particles are drawn into it, Mr. Koenigshofer has not proven that they make their way through the warming blanket and lead to surgical wound contamination. Present schlieren observations (Fig. 14) demonstrate that the Temperature Management Unit pulls air not only from below, but from around the entire unit.
3) "50-100 cfm are blown from the blanket into or near the sterile field, causing air to move horizontally…" This supposed horizontal air motion is not supported by evidence. In the

present report (Figs. 8 and 9) the distance of coherent motion of the microjets discharged by the Bair Hugger 52200 Blanket is found to be only a few cm.

4) "Air leaving the blanket at 100-110F will cause upward convective flow." Present evidence shows the temperature of air leaving the blanket to be only 90°F leaving the blanket, and nearly back to room temperature after a distance of a few cm. Schlieren visualizations further revealed no more apparent upward convective flow from the 3M Bair Hugger 52200 Blanket under laminar downflow conditions than from the HotDog REF B103 Blanket with which it was compared.
5) "The hot air will add to the surgeon's discomfort…" Given the rapid mix-out to near room temperature of the exhaust from the Bair Hugger blanket shown in Fig. 9 of the present report, this conclusion is unjustified.
6) "The heater in the Bair Hugger adds to the cooling load…" Present evidence shows that the exhaust air of the Bair Hugger Blanket mixes out rapidly with the surrounding air. Given the 24-27 ACH air exchange rate of an OR, the additional heat load from the Bair Hugger Blanket is actually trivial.

Summary of Opinions

1) A claim has been made [16] that "forced-air warming generate(s) convection currents that mobilise floor air into the surgical site area." Present experimental data belie that claim, proving that the effective "reach" of micro-jets in the exhaust of the 3M Bair Hugger Model 52200 Upper Body Temperature Management Blanket is only a few centimeters, which is far shorter than what would be required to reach to the OR floor.
2) The exhaust temperature of warm air from the Bair Hugger Blanket was assumed to be 41°C (106°F) by Elghobashi [17]. Present measurements (Fig. 9) show that it is only 32.5°C (90°F), and that it mixes out to a value near local room temperature within a distance of a few cm.
3) Even if the Bair Hugger blanket's exhaust air could reach the OR floor, it would, over that distance, be essentially completely mixed out with the surrounding air. It would thus have little or no residual buoyancy with which to rise to a height of perhaps 2 m in order to release bacteria-carrying particles into the surgical site, let alone to buck the 38 fpm downflow of clean air that opposes any such motion.
4) Schlieren observation of the 3M Bair Hugger 52200 Blanket and the (non-forced-air) HotDog Patient Warming REF B103 Blanket in use shows thermal convection rising from both, but in both cases the 38 fpm laminar downflow easily sweeps these convection currents away. There are no great differences in the visible thermal behavior of these two blankets in OR laminar downflow conditions.
5) Temperatures measured underneath the blankets and drapes of a mannequin being warmed by a Bair Hugger 52200 Blanket ranged from near room temperature up to a maximum of 28°C. These experimental values are much lower than those used by Prof. Elghobashi in his CFD analysis, and invalidate his findings.
6) The power units of Bair Hugger and HotDog patient warming blankets both release heat into the OR environment. The differences in the local flow patterns of these two power units that are visible to schlieren optics are unremarkable.
7) While we found no evidence that patient warming blankets (forced-air or not) produce airflows that promote contamination of the surgical wound site, the same cannot be said for OR personnel and some OR equipment. A surgeon bending over the surgical site generates an air recirculation zone that is likely to carry squames and bacteria. The rising thermal plume of OR staff standing near an overhead surgical lamp interacts with the dead-air zone produced by the lamp, setting the stage for squames and bacteria to drop into the surgical wound site. Some OR equipment, such as electrocautery pens, create their own rising, contamination-bearing thermal plumes. Based on our investigation, all of these sources are much more likely to carry bacteria-laden particles to the surgical wound site than are patient-warming blankets.

Gary S. Settles

June 15, 2017

References

[1] G.S. Settles, *Schlieren and shadowgraph techniques: Visualizing phenomena in transparent media*, Springer-Verlag, Berlin, 2001.

[2] H.E. Lewis, Colour photography of the convecting air next to the skin, *Journal of Physiology-London*, 188 (1967) 6P-7P

[3] H.E. Lewis, A.R. Foster, B.J. Mullan, R.N. Cox, R.P. Clark, Aerodynamics of the human microenvironment, *Lancet*, 293 (1969) 1273-1277

[4] R.P. Clark, R.N. Cox, An application of aeronautical techniques to physiology. 1. The human microenvironment and convective heat transfer, *Medical and Biological Engineering*, 12 (1974) 270-274.

[5] D. Grady, The mysterious cough, caught on film, *The New York Times*, Oct. 28, 2008, pp. D3.

[6] R.P. Clark, M.L. de Calcina-Goff, Some aspects of the airborne transmission of infection, *Journal of the Royal Society Interface*, 6 (2009) S767-S782.

[7] J.W. Tang, G.S. Settles, Coughing and aerosols, *New England Journal of Medicine*, 359 (2008) e19-e19.

[8] J.W. Tang, T.J. Liebner, B.A. Craven, G.S. Settles, A schlieren optical study of the human cough with and without wearing masks for aerosol infection control, *Journal of the Royal Society Interface*, 6 (2009) S727-S736.

[9] J.W. Tang, C.J. Noakes, P.V. Nielsen, I. Eames, A. Nicolle, Y. Li, G.S. Settles, Observing and quantifying airflows in the infection control of aerosol- and airborne-transmitted diseases: an overview of approaches, *Journal of Hospital Infection*, 77 (2011) 213-222.

[10] J.W. Tang, G.S. Settles, Schlieren imaging: A real-time, non-invasive method to visualize human exhaled airflows to assist aerosol infection control, *Influenza and Other Respiratory Viruses*, 5 (2011) 307-310.

[11] W. Whyte, B.H. Shaw, The effect of obstructions and thermals in laminar-flow systems, *Journal of Hygiene*, 72 (1974) 415-423.

[12] R.P. Clark, Skin scales among airborne particles, *Journal of Hygiene*, 72 (1974) 47-51.

[13] R.P. Clark, P.J. Reed, D.V. Seal, M.L. Stephenson, Ventilation conditions and air-borne bacteria and particles in operating theatres: proposed safe economies, *Journal of Hygiene*, 95 (1985) 325-335.

[14] W. Merzkirch, *Flow visualization*, Academic Press, New York, 1987.

[15] R.W. Hale, P. Tan, R.C. Stowell, D.E. Ordway, Development of an integrated system for flow visualization in air using neutrally-buoyant bubbles, Sage Action Inc., Ithaca, NY, 1971, AD-756691

[16] McGovern P, Albrecht M, Belani K, Nachtsheim C, Partington P, Carluke I, et al. Forced-air warming and ultra-clean ventilation do not mix. *J Bone Joint Surg Br*. 2011; 93(11):1537-44.

[17] S. Elghobashi, Effect of heated-air blanket on the dispersion of squames in an operating room, Expert Report MDL No. 15-2666 (JNE/FLN), 2017.

[18] *ASHRAE Handbook*, HVAC Applications, Ch. 8: health care Facilities, 2015

[19] Memarzadeh F, Manning AP. Comparison of operating room ventilation systems in the protection of the surgical site/Discussion. *ASHRAE Transactions*. 2002;108:3

[20] Sikka RS, Prielipp RC. Forced air warming devices in orthopaedics: A focused review of the literature. *J Bone Joint Surg-Am* 2014; 96A(24):7.
[21] Cook G, Int-Hout D. Air motion control in the hospital operating room. *ASHRAE Journal* 2009; 51(3):30-6
[22] D.R. Richardson, How to design fluid-flow distributors, *Chemical Engineering*, 68 (1961) 83-86.
[23] HVAC design manual for hospitals and clinics, 2 ed., ASHRAE, Atlanta, GA, 2013.
[24] B.A. Craven, G.S. Settles, A computational and experimental investigation of the human thermal plume, *Journal of Fluids Engineering*, 128 (2006) 1251-1258.
[25] W.L. Oberkampf, T.G. Trucano, Verification and validation in computational fluid dynamics, *Progress in Aerospace Sciences*, 38 (2002) 209-272.
[26] D. Koenigshofer, In re Bair Hugger forced air warming products liability litigation, Expert Report MDL No. 15-2666 (JNE/FLN), 2017.
[27] 3M™Bair Hugger™ Patient Warming Computational Fluid Dynamic Study, https://www.youtube.com/watch?v=QhzeInWlJ54

Curriculum Vitae of DR. GARY S. SETTLES

EDUCATION

Princeton University, Ph.D., January 1976, Aerospace and Mechanical Sciences.
University of Tennessee (Knoxville), B.S. 1971, Mechanical and Aerospace Engineering.

EXPERIENCE

June 2015 to present: Director of R&D, FloViz Inc., Port Matilda, PA. (Founded company in 1987.) FloViz Inc. is a small business dedicated to the visualization, measurement, and analysis of fluid flows, specializing in optical flow diagnostics, and offering several shadowgraph and schlieren optical instruments as products. FloViz Inc. also offers consulting services on fluid dynamics and heat transfer problems in industry, academia, and government.

July 1983 to June 2015: Pennsylvania State University, Mechanical & Nuclear Engineering Dept., University Park, PA: Distinguished Professor of Mechanical Engineering and Director, Gas Dynamics Laboratory. Established Gas Dynamics Laboratory for experimental high-speed fluid dynamics research. Principal Investigator of research grants from NASA, AFOSR, ONR, DOE, NSF, FAA, DHS and several industries on atomization and sprays, environmental fluid dynamics, explosive detection technology, shock/boundary layer interaction phenomena, supersonic mixing and vortex breakdown, flow visualization, industrial clean-room fluid dynamics, and the gas dynamics of advanced materials and manufacturing processes. Taught ME 320 (Basic Fluid Mechanics), ME 420 (Compressible Flow I), ME 520 (Compressible Flow II), and ME 597 (Experimental Methods for Graduate Students). Supervised 20 PhD students and many MSE students' research programs. Senior Member of the Graduate Faculty and former member of the PSU Graduate Council.

May 1977 to July 1983: Princeton University, Mechanical and Aerospace Engineering Department, Princeton, NJ: Research Engineer and Lecturer; Manager, Gas Dynamics Laboratory. Co Principal Investigator on several experimental studies of two and three dimensional turbulent boundary layer/shock wave interaction flows. Manager of Gas Dynamics Laboratory operations, contracts, and staff. Supervised the research programs of seven graduate and two undergraduate students. Taught the Laboratory section of MAE 335 (Compressible Fluid Flow), and MAE 512 (Experimental Methods).

July 1975 to May 1977: Princeton Combustion Laboratories, Division of Flow Research, Inc., Princeton, NJ: Research Scientist. Project Leader of a study to define a national program in energy efficient pump utilization; duties involved technical contribution to the study, project management, supervision and coordination of the work of a ten member Technical Consulting Group. Co investigator on experimental projects involving the design, construction, and operation of a ballistic piston gas compressor and the detonation of a fuel air cloud by means of pyrophoric compounds. Investigator of a study of handling sensitivity of malfunctioned primers, involving high speed photographic observation of explosive events.

July 1971 to July 1975: Princeton University, Aerospace and Mechanical Sciences Department, Gas Dynamics Laboratory, Princeton, NJ: Assistant in Research and Teaching. Involved in graduate program of study and research leading to the Ph.D. degree; Research topic:

compressible turbulent boundary layers, shock wave interactions, and flow separa¬tion; Advisor: Prof. S. M. Bogdonoff. Served as teaching assistant in undergraduate fluid mechanics and thermodynamics courses.

Summer 1970: NASA Ames Research Center, Air Breathing Propulsion Branch, Moffett Field, CA: Engineering Aide. Developed and applied two new optical flow measurement techniques to experiments in supersonic and hypersonic airflows. Was involved with work on numerical codes for turbulent boundary layer prediction and hypersonic testing of airbreathing inlet configurations.

Summer 1968 and 1969: The Boeing Company, Commercial Airplane Division, SST Aerodynamics Group and Advanced 747 Configurations Group, Seattle, WA: Student En¬gineer. Involved in analysis and test planning for elastic forebody loads and crossflow lift of the supersonic transport. Involved in wing and airfoil design and wind tunnel testing of the advanced 747 airplane configuration. Carried out design study for wing tip tank installation on 747.

Summer 1967: U. S. Naval Ordnance Laboratory, Aeroballistics Division, White Oak, Silver Spring, MD: Physical Science Aide. Involved in high speed wind tunnel testing and optical flow analysis. Assisted with experiments carried out in supersonic and hypersonic wind tunnels, shock tube, and aeroballistic range.

HONORS AND AWARDS

1970 Awarded AIAA National Undergraduate Student Award for research in flow visualization.

1971 Awarded NSF Traineeship

1986 Awarded Penn State Engineering Society (PSES) Award for Outstanding Research

1986 Awarded AIAA Service Citation for Associate Editorship of AIAA Journal, 1983 1985.

1987 - Elected Associate Fellow of AIAA

1990 - Awarded Departments Head's Outstanding Faculty Award, M.E. Dept., Penn State

1992 - Awarded Penn State Engineering Society (PSES) Premiere Researcher Award

2003 - Paper of the Year Award, Journal of Thermal Spray Technology, (with co-authors T. C. Hanson and C. M. Hackett)

2004 – ASME Freeman Scholar Award

2004 – Awarded the Tsuyoshi Asanuma Award for Outstanding Achievement in Flow Visualization by the Visualization Society of Japan

2005 – Award for Excellent Visualized Image in 2005 (Full-scale schlieren image of a rifle discharge) by the Visualization Society of Japan

2007 – Given the title of Distinguished Professor by Penn State University

2007 – Awarded the Science Writing Award for Professionals in Acoustics by the Acoustical Society of America

2007 – Elected Fellow of ASME

PROFESSIONAL SOCIETIES/ACTIVITIES

Member: American Institute of Aeronautics and Astronautics (AIAA, Associate Fellow), American Society of Mechanical Engineers (ASME), American Physical Society (APS), Society of Photo Optical Instrumentation Engineers (SPIE), American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE)

AIAA: Associate Editor, AIAA Journal, 1983 85. General Chairman, AIAA 16th Fluid & Plasma Dynamics Conference, 1983. Member of Fluid Dynamics Technical Committee 1980 83. Treasurer, Princeton Section 1980 82. Past Technical Program Committee Member, Conference Session Chairman, and Reviewer for numerous AIAA meetings and publications since 1974. National Student Award Winner 1970. Elected Associate Fellow 1987.

Member of International Program Committee, 3rd through 17th International Symposia on Flow Visualization, 1983-present.

PAST AND PRESENT INDEPENDENT RESEARCH ACTIVITIES

Founder of FLOVIZ, Inc., a small business devoted to research and engineering in fluid dynamics, 1987

Consultant to United Technologies Research Center on transonic shock wave/boundary layer interactions and flow visualization for wind tunnel testing.

Consultant to IBM Corp. on clean room aerodynamics, flow visualization, and contamination control.

Consultant on 3 dimensional flow visualization to the Boeing Aerodynamics Laboratory.

Consultant to the Singer Co., American Meter Division, on the development of a natural gas energy meter.

Consultant to Ketron, Inc., on the fluid mechanics of mine ventilation.

Consultant to Nassau Research, Inc., on fluid flow problems of acetylene torches.

Consultant to Princeton Combustion Research Laboratories on problems of industrial energy conservation and experimental and computational fluid mechanics.

Consultant to the Rosenblad Corporation on the fluid mechanics of large industrial equipment.

Consultant to Ion Track Instruments Inc. on airborne sampling of trace explosives

Consultant to Intertek Testing Services on schlieren and shadowgraph imaging for kitchen ventilation testing

Contributor on scientific photography, fluid mechanics, and combustion to various publications, museum exhibits, films, and television series including Scientific American, OMNI, Science Digest, Science et Vie, Newsweek, the Franklin Institute, the award winning film "Search for Solutions", the CBS science series "Universe", the NBC "Today Show," and CNN's "Science News." Schlieren photography work was also featured in the series "Scientific Imagery", on German Public Television (NDR), and in The Learning

Channel"s Series "Body Atlas." The world's largest stereoscopic schlieren system was set up to produce footage for the 1997 3D IMAX film "Hidden Dimension" Color schlieren photographs of the human cough, gunshots, and other phenomena have been reproduced in hundreds of books, magazines, and newspapers around the world.

JOURNAL AND PROPOSAL REVIEWER FOR:
Acoustics Australia
Advances in Physiology Education
AIAA Journal
European Journal of Physics
Experiments in Fluids
International Journal of Heat and Fluid Flow
Journal of the Acoustical Society of America
Journal of Biochemical and Biophysical Methods
Journal of Biomedical Optics
Journal of Fluid Mechanics
Journal of Fluids Engineering
Journal of Hazardous Materials
Journal of the Royal Society - Interface
Journal of Thermal Spray Technology
Journal of Turbulence
Journal of Visualization
Measurement Science and Technology
National Science Foundation
  -Chemical & Thermal Systems
  -Integrative Organismal Systems (Biology)
Optical Engineering
Review of Scientific Instruments
Particle and Particle Systems Characterization
Plasma Sources Science and Technology
Shock Waves
US Dept. of Energy Basic Energy Sciences Program

INVITED LECTURES AND SEMINARS

Seminar entitled "A Review of Experimental Research at the Princeton Gas Dynamics Laboratory" was presented in various versions at:
   California Institute of Technology (February 1981)
   United Technologies Research Center (March 1981)
   University of Tennessee Space Institute (August 1981)
   University of Texas (January 1982)
   Lockheed Georgia Co. (August 1982)
   Pennsylvania State University (March 1983)

Invited Survey Lecture entitled "The State-of-the-Art of Conventional Flow Visualization Techniques for Wind Tunnel Testing," presented at the NASA Workshop on Flow Visualization and Laser Velocimetry for Wind Tunnels, Hampton VA, March 1982.

Seminar entitled "Some Unusual Fluid Phenomena Visualized by the Schlieren Technique", presented at Rutgers University, October 1982.

Invited Keynote Lecture on "Flow Visualization Techniques for Practical Aerodynamic Testing," Presented at the Third International Symposium of Flow Visualization, Ann Arbor, MI, September 1983.

Seminar entitled "White Light Psuedo Color Encoding Optics for Flow Visualization," presented at Penn State Electrical Engr. Dept., October 1983.

Invited Survey Lecture entitled "Modern Developments in Flow Visualization," presented at AIAA 17th Fluid and Plasma Dynamics and Lasers Conference, Snowmass, CO, June 1984.

Invited Lectures on Shock/Boundary Layer Interactions and Flow Visualization were presented at the Beijing Institute of Aeronautics and Astronautics and the Beijing Institute of Aerodynamics, Beijing, China, July 1984.

Seminar Entitled "Visualization of Human Aerobiological Flows," presented at Hershey Medical Center, October 1984, and Penn State Chemical Engr. Dept., February 1985.

Seminar entitled "Color Schlieren Flow Visualization and Applications", presented at San Diego State University, Fall 1985.

Invited lecturer, University of Michigan Summer Short Course entitled, "Flow Visualization Techniques: Principles and Applications", yearly, 1986 to 1990.

Invited Paper (AIAA 86-1099), "Recent Skin Friction Techniques for Compressible Flows," presented at AIAA/ASME 4th Fluid Mechanics, Plasma Dynamics, and Lasers Conference, Atlanta, GA, May 1986.

Invited Lecture on "Flow Visualization: Images from Thin Air," presented at Meeting of SAE Williamsport, PA Group, April 1986.

Invited Seminar entitled "Flow Visualization in Microelectronics Manufacturing," presented at the IBM Thomas J. Watson Research Center, September 1987, and at IBM Federal Systems Division, October 1987.

Invited seminar entitled "Shock/Boundary Layer Interactions, Flow Visualization, and Instrumentation," presented at the USAF Arnold Engineering Development Center, Tullahoma, TN, March 1987.

Lehigh University Seminar in Engineering Science, "Application of Schlieren Optics in Fluid Mechanics and Heat Transfer," Feb. 20, 1987.

Invited Paper entitled "Visualization of High-Speed Flows at the Penn State Gas Dynamics Laboratory," presented at the 1988 International Conference on Applications of Lasers and Electro-Optics, Santa Clara, Oct. 30, 1988, with Metwally, O. M., Hsu, J. C., and Lu, F. K.

Invited Paper entitled "Swept Shock/Boundary-Layer Interactions -- Tutorial and Update," Invited AIAA Paper 90-0375, presented at the AIAA 28th Aerospace Sciences Meeting, Reno, NV, January 1990, co-authored with D. S. Dolling

Seminar entitled "Swept Shock/Boundary-Layer Interactions and Their Control", was presented at the Boeing Aircraft Co., Seattle, April 1991, and at NASA-Lewis research Center, June 1991.

Seminar entitled "A Review of Research at the Penn State Gas Dynamics Laboratory" was presented at:
Institute Saint-Louis, France (August1991)
ONERA Chalais-Meudon Laboratory (August 1991)
DLR-Gottingen (August 1991)

Seminar entitled "Schlieren Visualization of the Human-Body Thermal Plume," Mechanics & Fluid Mechanics Colloquium, Essen University, Germany, May 5, 1993.

Keynote Lecturer in NATO/AGARD Special Course on Shock Wave/Boundary Layer Interactions in Supersonic and Hypersonic Flows," Brussels, Belgium, 24-28 May, 1993.

Panelist, NSF National Young Investigator Selection (Fluid, Particulate, and Hydraulic Systems), March 1994.

Seminar entitled "Schlieren and Shadowgraph Techniques; Whence They Come and Where They are Headed," College of Engineering, Florida State University/Florida A&M University, Tallahassee FL, Jan. 14, 1998.

Invited Lecture entitled "Non-Traditional Fluid Dynamics: Adventures Beyond the Realm" presented at:

- American Physical Society, Division of Fluid Dynamics, 51st Annual Meeting, Nov. 22-24, 1998, Philadelphia, PA
- Stanford University, Mechanical Engineering Dept., March 10, 1999.
- University of Minnesota, Mechanical Engineering Dept., April 14, 1999.
- Florida State and Florida A&M Universities, College of Engineering, Tallahassee, FL, April 17, 2001
- University of Florida, Mechanical and Aerospace Engr. Dept., March 18, 2004

"Flow Visualization: New Tricks for an Old Dog," at Bucknell University, Nov. 5, 1999.

Mechanical & Nuclear Engineering Faculty Distinguished Lecture, Jan. 24, 2002, “Seeing the Invisible at Penn State: A 20-Year Retrospective,” Penn State University

The Joy Goodwin Lecture, entitled “The External Aerodynamics of Canine Olfaction,” presented at the Auburn University College of Veterinary Medicine on March 5, 2002.

Seminar entitled “Shock Waves in Aviation Security and Safety,” University of Virginia, October 18, 2001.

NASA Langley Research Center Colloquium, “Shock Waves in Aviation Security and Safety,” Tuesday, June 4, 2002.

Sigma Public Lecture Series Presentation, “Shock Waves in Aviation Security and Safety, “ Tuesday, June 4, 2002, Virginia Air & Space Center, Hampton, VA.

Settles, G. S., “True Confessions of an Experimentalist,” Invited Paper # 2003-4271, presented at AIAA Fluid Dynamics Conference, Orlando, FL, June 26, 2003.

“Sniffers,” ASME Freeman Scholar Lecture, presented at the ASME IMECHE Conference, Anaheim CA, Nov. 2004. Also presented as an invited lecture at Syracuse University, Nov. 4, 2005.

Invited Lecture “High-speed imaging of shock waves, and small-scale blast testing of materials,” presented at Lehigh University, April 7, 2006. A version of this lecture co-authored by student M. J.Hargather was also given at the US Army Research Laboratory in June 2006.

Invited Lecture entitled “The Aerodynamics of Canine Olfaction,” presented at UC Berkeley, Neuroscience Dept., Oct. 2, 2006.

The William C. Reynolds Memorial Lecture, entitled “Fluid Mechanics and Homeland Security,” presented at Stanford University Oct. 5, 2006.

Invited Lecture entitled “Sniffing Like a Dog to Improve Air Sensors,” presented at Syracuse University, Oct. 30, 2006.

Invited Lecture entitled “The Aerodynamics of Canine Olfaction,” presented at the Gordon Research Conference on Detecting Illicit Substances: Explosives and Drugs, September 16-21, 2007, Big Sky, Montana.

Invited Lecture entitled “Laboratory-scale blast testing and optical diagnostics for explosive characterization and materials testing” presented at the University of Illinois at Urbana-Champaign, March 28, 2008.

Invited Lecture entitled “Modern engineering applications of schlieren and shadowgraph optics,” presented at the University of Texas at Arlington, October 3, 2008.

Invited Lecture entitled “Videos and images from 25 years of teaching compressible flow,” presented at the 61st Annual Meeting of the American Physical Society Division of Fluid Dynamics, San Antonio, TX, Nov. 23-25, 2008.

Invited Lecture entitled “Imaging flows that are represented by hyperbolic PDEs,” Mathematics Dept., Penn State University, Feb. 20, 2009.

Invited Lecture entitled “The Art and Science of Flow Visualization – a different perspective,” presented at Lafayette College, Easton, PA, Feb. 23, 2009.

Invited Lecture entitled “Outdoor refractive optical methods for flow visualization and measurement,” presented at the University of Wyoming, April 23, 2009.

Invited Lecture entitled “The Aerodynamics of Canine Olfaction,” presented at the Gordon Research Conference on Detecting Illicit Substances: Explosives and Drugs, June 14-19, 2009, Les Diablerets, Switzerland. Co-authored with M. J. Hargather.

Invited Lecture entitled “Explosives Research,” presented at the Institut Saint-Louis, France, June 19, 2009.

Invited Lecture entitled “The Aerodynamics of Canine Olfaction,” presented in the Forensics Seminar Series at the University of Rhode Island, Nov. 13, 2009.

Invited Lecture entitled “The Art and Science of Refractive-Media Visualization by the Schlieren Method,” presented at ICCP10, MIT, Cambridge MA, March 30, 2010.

Invited Lecture entitled “The Aerodyanmics of Chemical Trace Sampling – A Brief Review,” Presented at Bruker-Daltonics Corp., Bilerica MA, March 30, 2010.

Invited Lecture entitled “PSU Gas Dynamics Lab/AEDC White OAK Collaboration (Plus a Little History), AEDC Tunnel 9, White Oak MD, April 9, 2010.

Invited Lecture entitled “Airborne Trace Sampling: Lessons Learned from the Dog’s Nose,” presented at the 2010 Annual Workshop on Trace Explosives Detection, Baltimore MD, April 27, 2010

Invited Keynote Lecture entitled “Important developments in schlieren and shadowgraph visualization during the last decade,” 14th International Symposium on Flow Visualization, Daegu, Korea, June 21-24, 2010.

Invited Lecture entitled “High-speed imaging of shock waves and laboratory-scale explosives research,” presented at the US Army Aberdeen Test Center, Oct. 27, 2010.

Invited Lecture entitled “Human scent, airborne trace detection, and how the dog’s nose works,” presented at the FBI Laboratory, Quantico VA, April 26, 2011.

Invited Lecture entitled “A human-wake-sampling portal for trace detection in security screening,” presented at the US Dept. of Homeland Security Headquarters, Science & Technology Directorate, Washington DC, June 10, 2011.

Invited Lecture entitled “Schlieren and shadowgraph techniques, with applications to 3M’s manufacturing and products,” Tech Forum Presentation, 3M Center, St. Paul MN, July 28, 2011.

Invited Lecture entitled “Penn State Research on Glass Fiber Imaging and Breakage,” presented at the Owens-Corning Corp. Science and Technology Center, Newark OH, Nov. 1, 2011

Invited Lecture entitled “Introduction to the Penn State Gas Dynamics Lab and Thoughts on Two Research Projects of Interest to Arcelormittal,” presented at Arcelormittal Corp. Global R&D, East Chicago, IN, Jan. 23, 2012.

Invited Lecture entitled “The Art and Science of Visualizing Flows by the Schlieren Optical Technique,” presented at Rochester Institute of Technology March 16, 2012.

Invited Lecture entitled “Supersonic gas jets, nozzles, high-speed digital imaging, and schlieren and shadowgraph techniques for flow visualization,” presented at the INDA RISE Conference, Baltimore, MD, October 25, 2012.

Invited Lecture entitled “The Science and Art of Visualizing Fluid Flows by Refractive Optical Techniques,” presented at the Penn State Fluid Dynamics Research Consortium March 21, 2013 and at the Mechanical Engineering Dept., University of Alabama, April 4, 2013.

Invited Lecture entitled “Shock Waves, Refractive Optics, and High-Speed Digital Video” was presented as the Southwest Mechanics Lecture at Oklahoma State University, the University of Oklahoma, Southern Methodist University, and the University of Texas at Arlington during the week of Oct. 5, 2014.

Invited Lecture entitled “Schlieren and Shadowgraph Optical Instruments,” presented at the Optical Science Center, University of Arizona, 7 April 2016.

PATENTS

US Patent 5,578,581, G.S. Settles, Inventor, entitled “Supersonic Abrasive Iceblasting Apparatus,” July 28, 1998, assigned to the Penn State Research Corp.

US Patent 5,975,996, G.S. Settles, Inventor, entitled “Abrasive Blast Cleaning Nozzle,” November 2, 1999, assigned to the Penn State Research Foundation.

US Patent 6,073,499, G.S. Settles, Inventor, entitled “Chemical trace detection portal based on the natural airflow and heat transfer of the human body,” June 13, 2000, assigned to the Penn State Research Foundation.

US Patent 6,171,656, G.S. Settles, Inventor, entitled "Method and apparatus for collecting overspray," Jan. 9, 2001, assigned to the Penn State Research Foundation.

US Patent 8,113,069, G.S. Settles, Inventor, entitled "Aerodynamic Sampler for Chemical/Biological Trace Detection," Feb. 14, 2012, assigned to the Penn State Research Foundation.

PUBLICATIONS

G. S. Settles and M. J. Hargather,"A review of recent developments in schlieren and shadowgraph techniques," Measurement Science & Technology, https://doi.org/10.1088/1361-6501/aa5748, 2017.

G. S. Settles and M. R. Fulghum, "The Focusing Laser Differential Interferometer, an Instrument for Localized Turbulence Measurements in Refractive Flows," Journal of Fluids Engineering, Vol. 138, 101402, 2016.

R. M. Young, J. F. Glusman, F. R. Svingala, and G. S. Settles, "Optical Shock Hugoniot Testing of Translucent Polymers," Ch. 3.5 of Elastomeric Polymers with High Rate Sensitivity, ed. R.H.S. Barsoum, NY:Elsevier, 2015.

B. A. Craven, M. J. Hargather, J. A. Volpe, S. P. Frymire, and G. S. Settles, "Design of a High-Throughput Chemical Trace Detection Portal That Samples the Aerodynamic Wake of a Walking Person," IEEE Sensors Journal, Vol. 14, No. 6, pp. 1852-1866, 2014.

M. J. Hargather, G. S. Settles, and S. Gogineni, "Optical diagnostics for characterizing a transitional shear layer over a supersonic cavity," AIAA Journal, Vol. 51 No. 12, pp. 2977-2982, 2013.

R. M. Young, M. J. Hargather, and G. S. Settles, "Shear stress and particle removal measurements of a round turbulent air jet impinging normally upon a planar wall," J. Aerosol Science, Vol. 62, pp.15-25, 2013.

Matthew R. Fulghum, Michael J. Hargather, and G. S. Settles, "An Integrated Impactor/Detector for a High-Throughput Explosive Trace Detection Portal," IEEE Sensors Journal, Vol. 13, No. 4, pp. 1252-1258, 2013.

M. J. Lawson, B. A. Craven, E. G. Paterson, and G. S. Settles, "A computational study of odorant transport and deposition in the canine nasal cavity: implications for olfaction," Chemical Senses Vol. 37, No. 6, pp. 553-566, 2012.

F. R. Svingala, M. J. Hargather, and G. S. Settles, "Optical techniques for measuring the shock Hugoniot using ballistic projectile and high-explosive shock initiation," International Journal of Impact Engineering, Vol. 50, No. 12, pp. 76-82, 2012.

M. Grujicic, T. He, B. Pandurangan, F. R. Svingala, G. S. Settles, and M. J. Hargather, "Experimental Characterization and Material-Model Development for Microphase-Segregated Polyurea: An Overview," Journal of Materials Engineering and Performance, Vol. 21, No. 1, pp. 2-16, 2012.

M. J. Hargather and G. S. Settles, "A comparison of three modern quantitative schlieren techniques," Optics and Lasers in Engineering 50 (1):8-17, 2012.

M. J. Hargather, M. E. Staymates, M. J. Madalis, D. J. Smith, and G. S. Settles, "The internal aerodynamics of cargo containers for trace chemical sampling and detection," IEEE Sensors Journal 11 (5):1184-1193, 2011.

M. J. Hargather, M. J. Lawson, G. S. Settles, and L. M. Weinstein, "Seedless velocimetry measurements by Schlieren Image Velocimetry," AIAA Journal 49 (3):611-620, 2011.

M. J. Hargather and G. S. Settles, "Background-oriented schlieren visualization of heating and ventilation flows: HVAC-BOS," Heating, Ventilation, Air-Conditioning & Refrigeration Research 17 (5):771-780, 2011.

J. W. Tang and G. S. Settles, "Schlieren imaging: A real-time, non-invasive method to visualize human exhaled airflows to assist aerosol infection control," Influenza and Other Respiratory Viruses 5 (Suppl. 1):307-310, 2011.

J. W. Tang, C. J. Noakes, P. V. Nielsen, I. Eames, A. Nicolle, Y. Li, and G. S. Settles, "Observing and quantifying airflows in the infection control of aerosol- and airborne-transmitted diseases: an overview of approaches," Journal of Hospital Infection 77 (3):213-222, 2011.

M. M. Biss and G. S. Settles, "On the use of composite charges to determine insensitive explosive material properties at the laboratory scale," Propellants Explosives Pyrotechnics 35 (5):452-460, 2010.

S. Y. Del Valle, R. Tellier, G. S. Settles, and J. W. Tang, "Can we reduce the spread of influenza in schools with face masks?" American Journal of Infection Control 38 (9):676-677, 2010.

M. J. Hargather and G. S. Settles, "Recent developments in schlieren and shadowgraphy." 27th AIAA Aerodynamic Measurement Technology and Ground Testing Conference, 28 June - 1 July 2010, Chicago, Illinois, Paper AIAA 2010-4206.

M. J. Hargather and G. S. Settles, "Background-oriented schlieren visualization of heating and ventilation flows: HVAC-BOS" Proc. 14th International Symposium on Flow Visualization, Daegu, Korea, June 21-24, 2010, ed. K. C. Kim, Paper no. 266.

G. S. Settles, “Important developments in schlieren and shadowgraph visualization during the last decade,” Proc. 14th International Symposium on Flow Visualization, Daegu, Korea, June 21-24, 2010, ed. K. C. Kim, Invited paper no. 267.

B. A. Craven, E. G. Paterson, and G. S. Settles. “The fluid dynamics of canine olfaction: a new explanation for macrosmia.” Journal of the Royal Society Interface, Vo. 7, No. 47, pp. 933-943, 2010.

M. J. Hargather and G. S. Settles. “Natural-background-oriented schlieren imaging.” Experiments in Fluids Vol. 48, No. 1, pp. 59-68, 2010.

J. W. Tang and G. S. Settles, “Coughing and masks” New Engand Journal of Medicine. Vol. 361, No. 26, p. e62, 2009.

G. S. Settles, E. Krause, and H. Fütterer, “Theodor Meyer – Lost pioneer of gas dynamics,” Progress in the Aerospace Sciences, Vol. 45, No. 6-8, pp. 203-210, 2009.

B. A. Craven, E. G. Paterson, and G. S. Settles. “Development and verification of a high-fidelity computational fluid dynamics model of canine nasal airflow,” Journal of Biomechanical Engineering, Vol. 131, No. 9, Article 091002, 2009.

M. J. Hargather, G. S. Settles, and M. J. Madalis, “Schlieren imaging of loud sounds and shock waves in air near the limit of visibility,” Shock Waves, Vol. 20, No. 1, pp. 9-17, 2010.

J.W. Tang, T.J. Liebner, B.A. Craven, and G.S. Settles, “A schlieren optical study of the human cough with and without wearing masks for aerosol infection control,” Journal of the Royal Society Interface, Vol. 6, pp. S727-S736, 2009.

M. J. Hargather and G. S. Settles. “Retroreflective shadowgraph technique for large-scale flow visualization.” Appied.Optics Vol. 48 No. 22, pp. 4449-4457, 2009.

M. J. Hargather, M. J. Lawson, G. S. Settles, L. M. Weinstein, and S. Gogenini, “Focusing-schlieren PIV measurements of a supersonic turbulent boundary layer” 47th AIAA Aerospace Sciences Meeting, 5 - 8 January 2009, Orlando, Florida, AIAA Paper 2009-69.

M. J. Hargather, G. S. Settles. "Laboratory-scale techniques for the measurement of a material response to an explosive blast." International Journal of Impact Engineering, Vol. 36, No. 7, pp. 940-947, 2009.

J. W. Tang and G. S. Settles, “Coughing and aerosols” New Engand Journal of Medicine Vol. 359 No. 15,p. e19, 2008.

M. J. Hargather, G. S. Settles, L. J. Dodson-Dreibelbis, and T. J. Liebner, “Natural-background-oriented schlieren imaging” presented at the 13th International Symposium on Flow Visualization, Nice, France, July 1-4, 2008, paper no. 275.

G. S. Settles, M. J. Hargather, M. J. Lawson, R. P. Bigger, and M. J. Madalis, “Schlieren imaging of shock waves in air at the extreme weak limit” presented at the 13th International Symposium on Flow Visualization, Nice, France, July 1-4, 2008, paper no. 277.

H. Kleine and G. S. Settles, “Artistic elements in visualizations of compressible flows,” presented at the 13th International Symposium on Flow Visualization, Nice, France, July 1-4, 2008, paper no. 302.

M. M. Biss, G. S. Settles, and S. R. Sanderson, “Differential schlieren-interferometry with a simple adjustable Wollaston-like prism,” Appied Optics, Vol. 47, No. 3, pp. 328-335, 2008.

H. Kleine and G. S. Settles, “The art of shock waves and their flowfields,” Shock Waves Vol. 17, No. 5, pp. 291-307, 2008.

M. J. Hargather and G. S. Settles, "Optical measurement and scaling of blasts from gram-range explosive charges." Shock Waves Vol. 17 No. 4, pp. 215-223, 2007.

J. Porter, B. A. Craven, R. M. Khan, S. J. Chang, I. Kang, B. Judkewitz, B. Judkewicz, J. A. Volpe, G. S. Settles, and N. Sobel, “Mechanisms of scent-tracking in humans, Nature Neuroscience Vol. 10 No. 1, pp.:27-29, 2007.

B. A. Craven, T. Neuberger, G. S. Settles, E. G. Paterson, A. G. Webb, E. M. Josephson, and E. E. Morrison, "Reconstruction and morphometric analysis of the nasal airway of the dog (Canis familiaris) and implications regarding olfactory airflow," Anatomical Record Vol. 290 No. 11, pp.1325-1340, 2007.

Michael J. Hargather, Gary S. Settles, and Joseph A. Gatto, “Gram-range explosive blast scaling and associated materials response,” Proc. 26th International Symposium on Shock Waves, July 15th-20th 2007, Göttingen, Germany.

M.M. Biss, M.J. Hargather, G.S. Settles, L.J. Dodson, and J.D. Miller, “High-speed digital shadowgraphy of shock waves from explosions and gunshots,” Proc. 26th International Symposium on Shock Waves, July 15th-20th 2007, Göttingen, Germany.

M. E. Staymates, G. S. Settles, K.-B. Shi, and Z.-W. Liu, “Supercontinuum laser illumination applied to traditional optical flow imaging methods,” Optics Communications, Vol. 273, 2007, pp. 252-255.

M. J. Hargather, G. S. Settles, J. A. Gatto, “Optical measurement, characterization, and scaling of blasts from gram-range explosive charges,” Proc. 4th International Aviation Security Technology Symposium, Washington, DC, November 28-December 1, 2006.

M. J. Hargather, G. S. Settles, J. A. Gatto, T. P. Grumstrup, and J. D.Miller, "Full-scale optical experiments on the explosive failure of a ULD-3 air cargo container," Proc. 4th International Aviation Security Technology Symposium, Washington, DC, November 28-December 1, 2006.

M. E. Staymates, D. J. Smith, and G. S. Settles, "The internal aerodynamics of cargo containers for trace explosives sampling," Proc. 4th International Aviation Security Technology Symposium, Washington, DC, November 28-December 1, 2006.

G. S. Settles, "On the fluid dynamicist as artist," Proc. 12th International Symposium on Flow Visualization, September 10-14, 2006, Göttingen, Germany.

G. S. Settles, G. Tremblay, J. M. Cimbala, L. J. Dodson, and J. D. Miller, "Fluid mechanics films in the 21st century," Proc. 12th International Symposium on Flow Visualization, September 10-14, 2006, Göttingen, Germany.

B.A. Craven and G.S. Settles, "A computational and experimental investigation of the human thermal plume" Journal of Fluids Engineering, Vol. 128, No. 6, November 2006, pp. 1251-1258.

J. A. Volpe and G. S. Settles, "Laser-induced gas breakdown as a light source for for schlieren and shadowgraph "PIV," Optical Engineering, Vol. 45, No. 8, Aug. 2006, pp. 080509-1 to 080509-3.

D. R. Jonassen, G. S. Settles, and M. D. Tronosky, "Schlieren 'PIV' for turbulent flows," Optics and Lasers in Engineering, Vol. 44, No. 3-4, pp. 190-207, 2006.

G. S. Settles, "High-speed imaging of shock waves, explosions and gunshots," American Scientist, Vol. 94, No 1, pp. 22-31, 2006.

G. S. Settles, "Fluid mechanics and homeland security," Annual Review of Fluid Mechanics, Vol. 38, pp. 87-110, 2006.

B. A. Edge, E. G. Paterson, and G. S. Settles, "Computational study of the wake and contaminant transport of a walking human," J.Fluids Eng., Vol. 127, No. 5, pp. 967-977, 2005.

G. S. Settles, T. P. Grumstrup, J. D. Miller, and J. A. Gatto, Full-scale high-speed Edgerton shadowgraphy of explosions and gunshots," Proc. 5th Pacific Symposium on Flow Visualization and Image Processing, Daydream Island, Australia, 27-29 September, 2005

S. P. Mates and G. S. Settles, "Experiments on Liquid Metal Atomization Using Close-Coupled Nozzles, Part 1: Gas Dynamic Behavior," Atomization and Sprays, Vol. 15, No. 1, pp. 19-40, 2005.

S. P. Mates and G. S. Settles, “Experiments on Liquid Metal Atomization Using Close-Coupled Nozzles, Part 2: Atomization Behavior,” Atomization and Sprays, Vol. 15, No. 1, pp. 41-59, 2005.

G. S. Settles, “Sniffers: Fluid-dynamic sampling for olfactory trace detection in nature and homeland security –The 2004 Freeman Scholar Lecture,” J. Fluids Eng. Vol, 127, No. 2, pp. 189-218, 2005.

G. S. Settles, L. J. Dodson, “Full-scale schlieren visualization of supersonic bullet and muzzle blast from firing a .30-06 rifle,” Journal of Visualization, Vol. 8, No. 1, 2005, p. 6.

G. S. Settles, T. P. Grumstrup, L. J. Dodson, J. D. Miller, and J. A. Gatto, “Full-scale high-speed schlieren imaging of explosions and gunshots,” Proc. 26th Intl. Conf. on High-Speed Photography and Photonics, Alexandria, VA, Sept. 20-24, 2004, D. L. Paisley, ed., Bellingham, WA:SPIE Press. Paper 5580-174, pp. 60-68.

G. S. Settles, “The Penn State Full-Scale Schlieren System,” Proc. 11th International Symposium on Flow Visualization, ed. T. J. Mueller and I. Grant, Notre Dame University, August 2004, paper 76.

Settles, G. S., Benwood, J. R., and Gatto, J. A., “High-Speed Cinematography of Internal Explosions for Aviation Security,” presented at the 24th International Symposium on Shock Waves, Beijing, July 2004.

B. H. Pandya, G. S. Settles, and J. D. Miller, “Schlieren Imaging of Shock Waves from a Trumpet,” J. Acoustical Soc. America, Vol. 114 Part 1, No. 6, Dec. 2003, pp. 3363-3367.

Hanson, T. C. and Settles, G. S., "Particle Temperature and Velocity Effects on the Porosity and Oxidation of an HVOF Corrosion-Control Coating," Journal of Thermal Spray Technology, Vol. 12, No. 3, Sept. 2003, pp.403-415.

L. M. Weinstein and G. S. Settles, “Schlieren,” Chapter 4 of Optical Metrology for Fluids, Combustion, and Solids, ed. C. Mercer, Kluwer Academic Press, July 2003, ISBN 1-4020-7407-7.

Settles, G. S., Benwood, J. R., and Gatto, J. A., “Optical Shock Wave Imaging for Aviation Security,” presented at the 4th ASME_JSME Joint Fluids Engineering Conference, Honolulu, Hawaii, July 6-11, 2003

Hartranft, T. J., and Settles, G. S.,"Sheet Atomization of Non-Newtonian Liquids,” Atomization and Sprays, Vol. 13, Nos. 2-3, March-June 2003, pp. 191-221.

Settles, G. S., “True Confessions of an Experimentalist,” Invited Paper # 2003-4271, AIAA Fluid Dynamics Conference, Orlando, FL, June 26, 2003.

G. S. Settles, B. T. Keane, B. W. Anderson, and J. A. Gatto, "Shock waves in aviation security and safety," Shock Waves, Vol. 12, No. 4, Jan. 2003, pp.267-275.

Settles, G. S., Kester, D. A., and Dodson-Dreibelbis, L. J., "The External Aerodynamics of Canine Olfaction," Chapter 23 of Sensors and Sensing in Biology and Engineering, ed. F.G. Barth, J.A.C. Humphrey, and T.W. Secomb, Springer, Vienna & NY, 2003, ISBN 3-211-83771-X, pp. 323-335.

Hanson, T. C., Hackett, C. M., and Settles, G. S., "Independent Control of HVOF Thermal Spray Temperature and Velocity," Journal of Thermal Spray Technology, Vol. 11, No. 1, March 2002, pp. 75-85.

Gary S. Settles, Heather C. Ferree, Michael D. Tronosky, and Zachary M. Moyer, and William J. McGann, "Natural Aerodynamic Portal Sampling of Trace Explosives from the Human Body," FAA 3rd International Symposium on Explosive Detection and Aviation Security, Nov. 26-30, 2001, Atlantic City, NJ.

G.S. Settles, B.T. Keane, B.W. Anderson, and J.A. Gatto, "High-Speed Imaging of Shock-Wave Motion in Aviation Security Research," FAA 3rd International Symposium on Explosive Detection and Aviation Security, Nov. 26-30, 2001, Atlantic City, NJ.

Settles, G. S., Schlieren and Shadowgraph Techniques; Visualizing Phenomena in Transparent Media, Springer-Verlag, Heidelberg, September 2001, reprinted 2006, ISBN 3540661557.

Settles, G. S., and Kester, D. A., "Aerodynamic sampling for landmine trace detection," presented at SPIE Aerosense Meeting, Orlando, April 2001, SPIE Vol. 4394 paper 108.

Settles, G. S., and McGann, W. J., "Potential for portal detection of human chemical and biological contamination," presented at SPIE Aerosense Meeting, Orlando, April 2001, SPIE Vol. 4378 paper 01.

Settles, G. S., "Process Gas Nozzles," Section 4.8 of the LIA Handbook of Laser Materials Processing, ed. J. F. Ready & D. F. Farson, Laser Institute of America and Magnolia Publishing Inc., Orlando Florida, 2001, pp. 155-156.

G. S. Settles, B. T. Keane, B. W. Anderson, and J. A. Gatto, "Shock waves in aviation security and safety," Proc. of the 23rd Intl. Symposium on Shock Waves, July 2001, Fort Worth, TX.

Settles, G. S., "Airflow Visualization in a Model Greenhouse," Proc. Plasticulture 2000, Proc. 15th Intl. Congr. for Plastics in Agriculture, Hershey, PA, Sept. 2000, pp. 88-98.

Kegerise, M. A., and Settles, G. S., "Schlieren Image-Correlation Velocimetry and its Application to Free-Convection Flows," presented at the 9th International Symposium on Flow Visualization, Edinburgh, Scotland, Aug. 2000.

Gowadia, H. A., and Settles, G. S., "The Natural Sampling of Airborne Trace Signals from Explosives Concealed upon the Human Body," Journal of Forensic Sciences, Vol. 46, No. 6, Nov. 2001, pp. 1324-1331.

S. P. Mates and G. S. Settles, "The Gas-Dynamic and Metal Atomization Performance of Two Different Close-Coupled Nozzles," in Powder Materials: Current Research and Industrial Practices, Ed. F.D.S. Marquis, The Minerals, Metals and Materials Society, Warrendale, PA, 1999, pp.19-38.

Settles, G. S., "Imaging Gas Leaks by using Schlieren Optics," Pipeline and Gas Journal, Vol. 229, No. 9, September 1999, pp. 28-30.

Settles, G. S., "Schlieren and Shadowgraph Imaging in the Great Outdoors," Proceedings of the 2nd Pacific Symposium on Flow Visualization and Image Processing, May 16-19, 1999, Honolulu, USA.

Bemis, B. L., and Settles, G. S., "Ultraviolet Imaging of the Anode Attachment in Transferred-Arc Plasma Cutting," IEEE Trans. on Plasma Science, Vol. 27, No. 1, Feb. 1999, pp. 44-45

Hartranft, T. J., and Settles, G. S., "High-Pressure Sheet Atomization of Non-Newtonian Fluids," Proceedings of the ILASS-Americas 12th Annual Conference on Liquid Atomization and Spray Systems, May 16-19, 1999, Indianapolis, IN.

Garg, S., and Settles, G. S., "Measurements of a Supersonic Turbulent Boundary Layer by Focusing Schlieren Deflectometry," Experiments in Fluids, Vol. 25, No. 3, pp. 254-264, 1998.

Settles, G. S., "HVOF Thermal Spray Velocity, Temperature, and Stainless Steel Coating Properties," presented at the 16th Symposium on Energy Engineering Sciences, Argonne National Labs, IL, May 13-15, 1998.

Settles, G. S., Miller, J. D., Hartranft, T. J., and Brandt, A. D., "Visualization And Collection of Overspray from Airless Spray Painting," Proceedings of the 8th International Symposium on Flow Visualization, Sorrento, Italy, Sept. 1-4, 1998, Paper No. 138.

Settles, G. S., Brandt, A. D., and Miller, J. D., "Full-Scale Schlieren Imaging of Shock Waves for Aviation Security Research," Proceedings of the 8th International Symposium on Flow Visualization, Sorrento, Italy, Sept. 1-4, 1998, Paper No. 30.

Bemis, B. L., and Settles, G. S., "Visualization of Liquid Metal, Arc, and Jet Interactions in Plasma Cutting of Steel Sheet," Proceedings of the 8th International Symposium on Flow Visualization, Sorrento, Italy, Sept. 1-4, 1998, ed. G. Carlomagno, Paper No. 108.

Settles, G. S., “Overspray Collection Technology for Robotic Spray Painting of Navy Ships,” TM 97-137, Applied Research Laboratory, Penn State University, January 1998.

Brandt, A. D., and Settles, G. S., “Effect of Nozzle Orientation on Gas Dynamics of Inert Gas-Laser Cutting of Mild Steel,” Journal of Laser Applications. Vol. 9, No. 6., December 1997, p. 269ff.

Naughton, J. W., Cattafesta, L. N. III, and Settles, G. S., “An Experimental Study of Compressible Turbulent Mixing Enhancement in Swirling Jets,” Journal of Fluid Mechanics, Vol. 330 (1997), pp. 271-305.

Settles, G. S., “Visualizing Full-Scale Ventilation Airflows,” ASHRAE Journal, Vol. 39, No. 7, July 1997, pp. 19-26.

Settles, G. S., “A Flow Visualization Study of Airless Spray Painting,” Proceedings of the ILASS-Americas 10th Annual Conference on Liquid Atomization and Spray Systems, May 18-21, 1997, Ottawa, Canada, pp. 145-149.

Scroggs, S. D., and Settles, G. S., "An Experimental Study of Supersonic Microjets," Experiments in Fluids, Vol. 21, pp. 401-409, 1996.

Settles, G. S., Gowadia, H. A., S. B. Strine, T. E. Johnson, “The Natural Aerodynamic Sampling of Trace Explosives from the Human Body,” Proc. of the 2nd FAA Symposium on Explosives Detection Technology and Aviation Security Technology Conference, 12-15 Nov. 1996, Atlantic City, NJ, ed. W. H. Makky, pp. 65-70.

Settles, G. S., and Geppert, S. T., “Redesigning Blasting Nozzles to Improve Productivity," Journal of Protective Coatings and Linings, Vol. 13, No. 10, October 1996, pp. 64-72.

Brandt, A., Scroggs, S. D., and Settles, G. S., “An Investigation of the Effect of Nozzle Design and Orientation on Gas Dynamic Interactions During Inert Gas-Laser Cutting of Mild Steel,” presented at ICALEO’96, 14-17 Oct. 1996, Detroit, MI.

Hackett, C. M. and Settles, G. S., "Independent Control of HVOF Particle Velocity and Temperature," Proceedings of the 9th National Thermal Spray Conference, ed. C. Berndt, ASM International, Materials Park, OH, Oct. 1996, pp. 665-673.

Mates, S. P., and Settles, G. S., "High-Speed Imaging of Liquid Metal Atomization by Two Different Close-Coupled Gas Atomization Nozzles," presented at the 1996 World Congress on Powder Metallurgy and Particulate Materials, Washington DC, June 16-21, 1996.

Garg, S., and Settles, G. S., "Unsteady Pressure Loads Generated by Swept Shock Wave/Boundary-Layer Interactions," AIAA Journal, June 1996, Vol. 34, No. 6, pp. 1174-1181.

Garrison, T. J., Settles, G. S., Narayanswami, N., Knight, D. D., and Horstman, C. C., "Flowfield Surveys and Computations of a Crossing-Shock Wave/Boundary Layer Interaction," AIAA Journal, Vol. 34, No. 1, Jan. 1996, pp. 50-56.

Garrison, T. J., Settles, G. S., and Horstman, C. C., "Measurements of the Triple Shock Wave/Turbulent Boundary Layer Interaction," AIAA Journal, Vol. 34, No. 1, Jan. 1996, pp. 57-64.

Knight, D., Garrison, T., Settles, G., Zheltovodov, A., Maksimov, A., Shevchenko, A., and Vorontsov, S., Asymmetric Crossing Shock Wave - Turbulent Boundary Layer Interaction, AIAA Journal, Vol. 33, No. 6, Dec. 1995, pp.2241-2249.

Settles, G. S., Hackett, E. B., Miller, J. D., and Weinstein, L. M., "Full-Scale Schlieren Flow Visualization," in Flow Visualization VII, ed. J. P. Crowder, Begell House, New York, Sept. 1995, pp. 2-13.

Hackett, C. M. and Settles, G. S., "Research on HVOF Gas Shrouding for Coating Oxidation Control," Proceedings of the 8th National Thermal Spray Conference, ASM International, Houston, September 11-15, 1995, pp. 21-29.

Hackett, C. M. and Settles, G. S., "The Influence of Nozzle Design on HVOF Spray Particle Velocity and Temperature," Proceedings of the 8th National Thermal Spray Conference, ASM International, Houston, September 11-15, 1995, pp. 135-140.

Connelly, J. M, Gatto, J. A., and Settles, G. S., "An Assessment of the Aerodynamic Efficiency of the CPAD Holdings Ltd. Explosives Detection Portal," US Dept. of Transportation Report DOT/FAA/CT-95/45, July 1995, FAA Technical Center, Atlantic City, NJ.

Hackett, C. M. and Settles, G. S., "The HVOF Thermal Spray: Materials Processing from a Gas Dynamics Perspective," AIAA Paper 95-2207, AIAA 26th Fluid Dynamics Conference, San Diego, June 1995.

Mates, S. P., and Settles, G. S., "A Flow Visualization Study of the Gas Dynamics of Liquid Metal Atomization Nozzles," 1995 International Conference on Powder Metallurgy and Particulate Materials, Seattle, May 14-17, 1995.

Settles, G. S., and Garg, S.,"A Scientific View of the Productivity of Abrasive Blasting Nozzles," Journal of Protective Coatings and Linings, April 1995, pp. 28-41, 101-102.

Knight, D., Garrison, T., Settles, G., Zheltovodov, A., Maksimov, A., Shevchenko, A., and Vorontsov, S., Asymmetric Crossing Shock Wave - Turbulent Boundary Layer Interaction, AIAA Paper 95-0231, January 1995.

Settles, G. S., and Garg, S.,"A Scientific View of the Productivity of Abrasive Blasting Nozzles," Proceedings of the Steel Structures Painting Council 1994 International Conference, Atlanta, November 11-17, 1994, pp. 12-19.

Hackett, C. M., Settles, G. S., and Miller, J. D., "On the Gas Dynamics of HVOF Thermal Sprays," Journal of Thermal Spray Technology, Vol. 3, No. 3, September 1994, pp. 299-304.

Knight, D.D., Narayanswami, N., Garrison, T. J., and Settles, G. S., "Investigation of Crossing Shock Wave-Turbulent Boundary Layer Interaction," paper presented at Intl. Conf. on Methods of Aerophysical Research, Novosibirsk, Russia, August 22-24, 1994.

Settles, G. S., and Dodson, L. J., "Supersonic and Hypersonic Shock/Boundary-Layer Interaction Database," AIAA Journal, Vol. 32, July 1994, pp. 1377-1383.

Naughton, J. W., and Settles, G. S., "A Theoretical Framework for Mixing Layers Surrounding Compressible Turbulent Swirling Jets, " AIAA Paper 94-2245, June 1994.

Garrison, T. J., Settles, G. S., and Horstman, C. C., "Measurements and Computation of the Triple Shock Wave/Turbulent Boundary Layer Interaction," AIAA Paper 94-2274, June 1994.

Garrison, T. J., Settles, G. S., Narayanswami, N., and Knight, D. D., "Laser-Interferometer Skin Friction Measurements of Crossing-Shock-Wave/Turbulent-Boundary-Layer Interactions," AIAA Journal, Vol. 32, June 1994, pp. 1234-1241.

Garrison, T. J., Settles, G. S., Narayanswami, N., Knight, D. D., and Horstman, C. C., "Comparison of Flowfield Surveys and Computations of a Crossing-Shock Wave/Boundary Layer Interaction," AIAA Paper 94-2273, June 1994.

Hackett, C. M. and Settles, G. S., "Turbulent Mixing of the HVOF Thermal Spray and Coating Oxidation," Proceedings of the National Thermal Spray Conference, Boston, June 20-24, 1994.

Lee, Y., Settles, G. S., and Horstman, C. C., "Heat Transfer Measurements and Computations of Swept-Shock-Wave/Boundary-Layer Interactions, AIAA Journal, Vol. 32, No. 4, April 1994, pp. 726-734.

Garrison, T. J., Settles, G. S., Narayanswami, N., and Knight, D. D., "Structure of Crossing Shock-Wave/ Turbulent Boundary-Layer Interactions," AIAA Journal, Vol. 31, Dec. 1993, pp. 2204-2211.

Settles, G. S., "Swept Shock/Boundary Layer Interactions - Scaling Laws, Flowfield Structure, and Experimental Methods" in AGARD Report 792, US North Atlantic Treaty Organization, Advisory Group for Aerospace Research and Development, August 1993, pp. 1-1 to 1-40.

Garrison, T. J., Settles, G. S., Narayanswami, N., and Knight, D. D., "Laser-Interferometer Skin Friction Measurements of Crossing-Shock-Wave/Turbulent-Boundary-Layer Interactions," AIAA Paper 93-3072, July 1993.

Knight, D.D., Horstman, C.C., Settles, G.S., and Zheltovodov, A.,A., "3-D Shock Wave Turbulent Boundary Layer Interactions Generated by a Single Fin," Preprint 1-93, Institute of Theoretical and Applied Mechanics, Russian Academy of Sciences, Novosibirsk, June 23, 1993.

Hackett, C. M., Settles, G. S., and Miller, J. D., "On the Gas Dynamics of HVOF Thermal Sprays," Proceedings of the National Thermal Spray Conference, Anaheim, CA, June 7-11, 1993.

Naughton, J. W., Cattafesta, L. N. III, and Settles, G. S., "A Miniature, Fast-Response Five-Hole Probe for Supersonic Flowfield Measurements," AIAA Journal, Vol. 31, March 1993, pp. 453-458.

Garrison, T. J., and Settles, G. S., "Interaction Strength and Model Geometry Effects on the Structure of Crossing Shock-Wave/Turbulent Boundary-Layer Interactions," AIAA Paper 93-0780, Jan. 1993.

Naughton, J. W., and Settles, G. S., "Experiments on the Enhancement of Compressible Mixing via Streamwise Vorticity, Part I - Vortex Strength Assessment and Seed Particle Dynamics," AIAA Paper 93-0742, Jan. 1993.

Alvi, F. S., Settles, G. S., and Weinstein, L. M., "A Sharp-Focusing Schlieren Optical Deflectometer," AIAA Paper 93-0629, Jan. 1993.

Garg, S., and Settles, G. S., "Wall Pressure Fluctuations Beneath Swept Shock Wave/Boundary-Layer Interactions," AIAA Paper 93-0384, Jan. 1993.

Knight, D. D., Badekas, D., Horstman, C. C., and Settles, G. S., "Quasiconical Flowfield Structure of the Three-Dimensional Single Fin Interaction," AIAA Journal, Vol. 30, Dec. 1992, pp. 2809-2816.

Settles, G. S., "An Overview of Planar Laser Scattering for the Visualization of High-Speed Flows," in Flow Visualization VI, ed. Y. Tanida et al., Springer-Verlag, 1992, pp. 628-633.

Alvi, F. S., and Settles, G. S., "Physical Model of the Swept Shock Wave/ Boundary-Layer Interaction Flowfield," AIAA Journal, Vol. 30, Sept. 1992, pp. 2252-2258.

Zheltovodov, A. A., Borisov, A. V., Knight, D. D., Horstman, C. C., and Settles, G. S., "The Possibilities of Numerical Simulation of Shock Waves/Boundary layer Interaction in Supersonic and Hypersonic Flows," Proc. Intl. Conf. on the Methods of Aerophysical Research, Inst. of Theoretical and Applied Mechanics, Russian Academy of Sciences, Siberian Div., Novosibirsk, Russia, August 31- Sept. 4, 1992, pp. 164-170.

Lee, Y., Settles, G. S., and Horstman, C. C., "Heat Transfer Measurements and CFD Comparison of Swept Shock Wave/Boundary-Layer Interactions," AIAA Paper 92-3665, July 1992.

Garrison, T. J., Settles, G. S., Narayanswami, N., and Knight, D. D., "Structure of Crossing Shock-Wave/ Turbulent Boundary-Layer Interactions," AIAA Paper 92-3670, July 1992.

Naughton, J. W., and Settles, G. S., "Experiments on the Enhancement of Compressible Mixing via Streamwise Vorticity, Part I - Optical Measurements," AIAA Paper 92-3549, July 1992.

Naughton, J. W., Cattafesta, L. N. III, and Settles, G. S., "A Miniature, Fast-Response 5-Hole Probe for Supersonic Flowfield Measurements," AIAA Paper 92-0266, Jan. 1992.

Cattafesta, L. N. III, and Settles, G. S., "Experiments in Shock/Vortex Interaction," AIAA Paper 92-0315, Jan. 1992.

Garrison, T. J., and Settles, G. S., "Flowfield Visualization of Crossing Shock-Wave/Boundary Layer Interactions," AIAA Paper 92-0750, Jan. 1992.

Hsu, J. C., and Settles, G. S., "Holographic Flowfield Density Measurements in Swept Shock-Wave/Turbulent Boundary-Layer Interactions," AIAA Paper 92-0746, Jan. 1992.

Kim, K-S, Lee, Y., Alvi, F. S., and Settles, G. S., "Skin-Friction Measurements and Computational Comparison of Swept Shock/Boundary-Layer Interactions," AIAA Journal, Vol. 29, October 1991, pp. 1643-1650.

Kim, K-S, Lee, Y., and Settles, G. S., "Laser Interferometer/Preston Tube Skin-Friction Comparison in Shock Boundary-Layer Interaction," AIAA Journal, Vol. 29, June 1991, pp. 1007-1008.

Horstman, C. C., Settles, G. S., and Dodson, L. J., "Hypersonic Shock-Wave Turbulent Boundary-Layer Interaction Flows: Experiment and Computation," Paper # 209, 10th National Aerospace Plane Symposium, April 1991.

Settles, G. S., and Dodson, L. J., "Hypersonic Shock/Boundary-Layer Interaction Database," NASA CR 177577, 1991.

McIntyre, S. S., Stanewsky, E., and Settles, G. S., "An Optical Deflectometer for Turbulence Measurements," Proceedings of the 14th ICIASF Congress, Rockville, MD, Oct. 27-31, 1991.

Settles, G. S., and Dodson, L. J., "Hypersonic Shock/Boundary-Layer Interaction Database," AIAA Paper 91-1763, June 1991.

McIntyre, S. S., and Settles, G. S., "Optical Experiments on Compressible Turbulent Mixing Layers," AIAA Paper 91-0623, presented at the AIAA 29th Aerospace Sciences Meeting, Reno, NV, January 1991.

Knight, D. D., Settles, G. S., and Horstman, C. C., "3-D Shock Wave-Turbulent Boundary-Layer Interaction Generated by a Sharp Fin at Mach 4," AIAA Paper 91-0648, presented at the AIAA 29th Aerospace Sciences Meeting, Reno, NV, January 1991.

Settles, G. S., Alvi, F. S., and Hsu, J. C., "On the Shock-Bifurcation/Jet-Impingement Structure of Swept Interactions and related Flowfields," in Separated Flows and Jets, ed. V.V. Kozlov and A. V. Dovgal, IUTAM Symposium, Novosibirsk, USSR, July, 1990, Springer-Verlag, Berlin, 1991.

Alvi, F. S., and Settles, G. S., "A Parametric Study of Swept Shock Wave/Turbulent Boundary Layer Interaction Structures Using White-Light Conical Shadowgraphy," AIAA Paper 90-1644. July 1990.

Settles, G. S., and Dolling, D. S., "Swept Shock/Boundary-Layer Interactions -- Tutorial and Update," Invited AIAA Paper 90-0375, January 1990.

Lu, F. K., and Settles, G. S., "Upstream Influence Scaling of Fin-Generated Shock Wave Boundary-Layer Interactions," AIAA Paper 90-0376, presented at AIAA 28th Aerospace Sciences Meeting, Reno NV, Jan. 1990.

Kim, K-S., Lee, Y., Alvi, F. S., Settles, G. S., and Horstman, C. C., "Laser Skin Friction Measurements and CFD Comparison of Weak-to-Strong Swept Shock/Boundary Layer Interactions," AIAA Paper 90-0378, presented at the AIAA 28th Aerospace Sciences Meeting, Reno, NV, January 1990.

Deng, X-Y., and Settles, G. S., "A Test of the Independence Principle in Swept Cylindrical Shock Wave/Turbulent Boundary layer Interactions," Acta Aerodynamica Sinica, Vol. 7, Dec. 1989, pp. 442-448.

Hsu, J. C., and Settles, G. S., "Holographic Interferometry of Swept Shock/Boundary Layer Interactions," presented at the 5th International Symposium on Flow Visualization, Prague, Czechoslovakia, 21-25 August, 1989.

Settles, G. S., and Lu, F. K., "A Microcomputer-Based Data-Acquisition System for a Supersonic Wind-Tunnel Laboratory," presented at the 4th Asian Congress of Fluid Mechanics, August 19-23, 1989, Hong Kong.

Settles, G. S., "Aerospace and Wind Tunnel Testing," Chapter 25 of Handbook of Flow Visualization, ed. W.-J. Yang, Hemisphere Press, Washington, 1989, (pp. 395-408).

Settles, G. S., "Indoor Environments," Chapter 37 of Handbook of Flow Visualization, ed. W.-J. Yang, Hemisphere Press, Washington, 1989, (pp. 619-626).

Naughton, J. W., Cattafesta, L. N., and Settles, G. S., "An Experimental Study of the Effect of Streamwise Vorticity on Supersonic Mixing Enhancement," AIAA Paper 89-2456, presented at the AIAA/ASME/SAE/ASEE 25th Joint Propulsion Conference, Monterey, CA, July 10-14, 1989.

Hsu, J. C., and Settles, G. S., "Measurements of Swept Shock Wave/Turbulent Boundary Layer Interactions by Holographic Interferometry," AIAA Paper 89-1849, presented at the AIAA 20th Fluid Dynamics, Plasma Dynamics and Lasers Conference, Buffalo NY, June 12-14, 1989.

Lu, F. K., and Settles, G. S., "Inception Length to a Fully-Developed Fin-Generated Shock Wave Boundary-Layer Interaction," AIAA Paper 89-1850 and AIAA Journal, Vol. 23, May 1991, pp. 758-762.

Lu, F. K., and Settles, G. S., "Color Surface-Flow Visualization of Fin-Generated Shock-Wave Boundary-Layer Interactions," Experiments in Fluids, March 1990, Vol 8, No. 6, pp 352-354.

Denger, G. R., and Settles, G. S., "A Flow Visualization Study of Silicon Wafer Spray Development Uniformity," Proc. 19th Annual Mtg. of the Fine Particle Soc., Santa Clara, July 1988.

Metwally, O. M., and Settles, G. S., "An Experimental Study of Shock Wave/Vortex Interaction," AIAA Paper 89-0082, AIAA 27th Aerospace Sciences Meeting, Reno, NV, January 9, 1989.

Chuang, C. L., Cherng, D. L., Hsieh, W. H., Settles, G. S., and Kuo, K. K., "Study of Flowfield Structure in a Simulated Solid-Propellant Ducted Rocket Motor," AIAA Paper 89-0011, AIAA 27th Aerospace Sciences Meeting, Reno, NV, January, 1989.

Metwally, O. M., and Settles, G. S., "Interaction of a Supersonic Streamwise Vortex and a Normal Shock Wave," 41st Annual Meeting of the American Physical Society Division of Fluid Dynamics, Buffalo, NY, November 20-22, 1988.

Metwally, O. M., and Settles, G. S., "Measurements of a Supersonic Turbulent Vortex," Proc. 11th Symposium on Turbulence, Rolla, Missouri, October 17-19, 1988, Paper A31.

Chuang, C. L., Cherng, D. L., Hsieh, W. H., Settles, G. S., and Kuo, K. K., "Flow Visualization of a Simulated Solid-Propellant Ducted Rocket Motor," Proc. 25th JANNAF Combustion Meeting, October 24-28, 1988, Huntsville, Alabama.

Settles, G. S., Metwally, O. M., Hsu, J. C., and Lu, F. K., "Visualization of High-Speed Flows at the Penn State Gas Dynamics Laboratory," Proc. 1988 International Conference on Applications of Lasers and Electro-Optics, Santa Clara, Oct. 30, 1988, Laser Inst. of America Vol. 67, pp. 95-101.

McIntyre, S. S., Settles, G. S., Schmidt, M. C., and Via, G. G., "A Flow Visualization Study of Nonuniformities of Wafer Development in a Recirculating Tank," Proc. 9th International Symposium on Contamination Control, Los Angeles, Sept. 26-30, 1988, pp. 612-615.

Lu, F. K., and Settles, G. S., "Structure of Fin-Shock/Boundary-Layer Interactions by Laser Light-Screen Visualization," AIAA Paper 88-3803, First National Fluid Dynamics Congress, Cincinnati, OH, July 1988.

Fung, Y-T, Settles, G. S., and Ray, A., "Microprocessor Control of High-Speed Wind Tunnel Stagnation Pressure," AIAA Paper 88-2062, AIAA Aerodynamic Testing Conference, San Diego, May 1988.

Kim, K-S, and Settles, G. S., "Skin Friction Measurements by Laser Interferometry in Swept Shock/ Turbulent Boundary-Layer Interactions," AIAA Paper 88-0497, Jan. 1988, and AIAA Journal, Vol. 28, Jan. 1990, pp. 133-139.

Kim, K.-S., and Settles, G. S., "Skin Friction Measurements by Laser Interferometry," Ch. 3 of AGARDograph No. 315, A Survey of Measurements and Measuring Techniques in Rapidly Distorted Compressible Turbulent Boundary Layers, eds. H. H. Fernholz, A. J. Smits, and J.-P. Dussauge, November 1988.

Settles, G. S., and Via, G. G., "Measurement and Control of Particle-Bearing Air Currents in a VLF Clean Room," in Particles in Gases and Liquids 1, Detection, Characterization, and Control, ed. K. L. Mittal, Plenum Press, New York, 1989, pp. 185-194.

Lu, F. K., Settles, G. S., and Horstman, C. C., "Mach Number Effects on Conical Surface Features of Swept Shock Boundary-Layer Interactions," AIAA Paper 87-1365, June 1987, and AIAA Journal, Vol. 28, Jan. 1990, pp. 91-97.

Settles, G. S., Huitema, B. C., McIntyre, S. S., and Via, G. G., "Visualization of Clean Room Flows for Contamination Control in Microelectronics Manufacturing," Flow Visualization IV, ed. C. Veret, Hemisphere Press, 1987, pp. 833-838.

Settles, G. S., and Via, G., "A Portable Schlieren Optical System for Clean Room Applications," in Proc. 8th International Symposium on Contamination Control, Milan, Italy, Sept. 1986, pp. 381-392 and The Journal of Environmental Sciences, Vol 30, No 5, Sept., 1986, pp. 17-21.

Heinsohn, R. J., Yu, S. T., Merkle, C. L., Settles, G. S., and Huitema, B. C., "Viscous Turbulent Flow in Push Pull Ventilation Systems," in Ventilation '85, ed. H. D. Goodfellow, Elsevier Press, 1986, pp. 529 566.

Settles, G. S., "Modern Developments in Flow Visualization," Invited Survey Paper No. AIAA 84 1599, and AIAA Journal, Vol. 24, No. 8, August, 1986, pp. 1313 1323.

Settles, G. S., Horstman, C. C., and McKenzie, T. M., "Experimental and Computational Study of a Swept Compression Corner Interaction Flowfield," AIAA Journal, Vol. 24, No. 5, May, 1986, pp. 744 752.

Settles, G.S., "Recent Skin Friction Techniques for Compressible Flows," Invited Survey Paper No. AIAA 86 1099, May, 1986.

Settles, G. S., and Kimmel, R. L., "Similarity Conditions of Conical Shock Wave/Turbulent Boundary Layer Interactions," AIAA Journal, Vol. 24, No. 1, January, 1986, pp. 47 53.

Settles, G. S., "Moving Beyond Light Shows: A New Concept in Color Music Displays," Mix Magazine, Vol. 9, No. 10, October, 1985, pp. 48 53.

Settles, G. S., and Lu, Frank K., "Conical Similarity of Shock/Boundary Layer Inter- actions Generated by Swept and Unswept Fins," AIAA Journal, Vol. 23, No. 7, July, 1985, pp. 1021 1027.

Settles, G. S., "On the Inception Lengths of Swept Shock Wave/Turbulent Boundary Layer Interactions,in "Turbulent Shear Layer/Shock Wave Interactions," ed. J. Delery, Springer Verlag Publishing, Berlin, 1986, pp. 203 213.

Settles, G. S., and Dolling, D. S., "Swept Shock Wave Boundary Layer Interactions," in "Tactical Missile Aerodynamics," eds. M. J. Hemsch and J. N. Nielsen, Vol. 104 of AIAA Progress in Astronautics and Aeronautics Series, September, 1986, pp. 297 379.

Settles, G. S., "Colour Coding Schlieren Techniques for the Optical Study of Heat and Fluid Flow," in the International Journal of Heat and Fluid Flow, Vol. 6, No. 1, March 1985, pp. 3 15.

Schmidt, M. C., and Settles, G. S., "Alignment and Accuracy of the Conical Shadowgraph Flow Visualization Technique," Experiments in Fluids, Vol. 4, No. 2, pp. 93 96.

Settles, G. S., "Flow Visualization Techniques for Practical Aerodynamic Testing," in Flow Visualization III, ed. W. J. Yang, Hemisphere Press, New York, 1985, pp. 306 315.

Settles, G. S., and Kuhns, J. W., "Visualization of Airflow and Convection Phenomena About the Human Body," Bull. of the American Physical Soc., Vol. 29, No. 9, 1984, p. 1515.

Settles, G. S., "Large Field Color Schlieren Visualization of Transient Fluid Phenomena," Bull. American Physical Society, Vol. 28, No. 9, 1983, p. 1404.

Settles, G. S., "The State of the Art of Conventional Flow Visualization Techniques for Wind Tunnel Testing," in NASA CP 2243, eds. W. W. Hunter and J. T. Foughner, NASA, 1982, pp. 9 26.

Settles, G. S., and Teng, H. Y., "Cylindrical and Conical Flow Regimes of Three Dimen¬sional Shock Wave/Turbulent Boundary Layer Interactions," AIAA Paper 82 987, and AIAA Journal, Feb. 1984, pp. 194 200.

Settles, G. S., and Teng, H. Y., Flow Visualization Techniques for 3D Shock Wave/ Turbulent Boundary Layer Interactions," AIAA Paper 82 229, Jan. 1982, and AIAA Journal, March 1983, pp. 390 397.

Settles, G. S., "Schlieren Photography," Technical Photography, Vol. 14, No. 2, February 1982, pp. 35 41.

Settles, G. S., "Hidden Frenzy," (popular article on flow visualization and turbulence), Science Digest, Vol. 89, Aug. 1981, pp. 44 49, 117.

Settles, G. S., Perkins, J. J., and Bogdonoff, S. M., "Upstream Influence Scaling of 2D and 3D Shock/Turbulent Boundary Layer Interactions at Compression Corners, "AIAA Paper 81 0334 and AIAA Journal, June 1982, pp. 782 789.

Horstman, C. C., Settles, G. S., Williams, D. R., and Bogdonoff, S. M., "A Reattaching Free Shear Layer in Compressible Turbulent Flow A Comparison of Numerical and Experimental Results," AIAA Paper 81 0333, January 1981, and AIAA Journal, January 1982, pp. 79 85.

Arasteh, D. T., Nall, D. H., Harrje, D. T., and Settles, G. S., "Performance of a Selective Surface Water Wall Retrofit," Proc. 5th National Passive Solar Energy Conference, Amherst, MA, October 19 24, 1980.

Settles, G. S. and Bogdonoff, S. M., "Separated Flow and Boundary Layer Research," Report No. 1494, Princeton University, Mechanical and Aerospace Engineering Dept., Gas Dynamics Laboratory, October 1980.

Settles, G. S., "Color Schlieren Optics A Review of Techniques and Applications," Proceedings of the International Symposium on Flow Visualization, Sept. 9 12, 1980, Bochum, Germany, and Flow Visualization II, ed. W. Merzkirch, Hemisphere Press, New York, 1982, pp. 749 762.

Settles, G. S., Gilbert, R. B. and Bogdonoff, S. M., "Data Compilation for Shock Wave/ Turbulent Boundary Layer Interaction Experiments on Two Dimensional Compression Corners," Princeton University MAE Dept. Report No. 1489, August 1980.

Settles, G. S., Carlson, A. B. and Harrje, D. T., "An Optical Study of Thermal Convection in a Passive Solar Heated Room," ASME Paper 80 C2/Sol 1, 1980.

Settles, G. S., Baca, B.K., Williams, D. R. and Bogdonoff, S. M., "A Study of Reattachment of a Free Shear Layer in Compressible Turbulent Flow," AIAA Paper 80 1408, July 1980, and AIAA Journal, January 1982, pp. 60 67.

Settles, G. S., Perkins, J. J. and Bogdonoff, S. M., "Investigation of Three Dimensional Shock/Boundary Layer Interactions at Swept Compression Corners," AIAA Journal, Vol. 18, No. 6, July 1980, pp. 779.

Settles, G. S., Fitzpatrick, T. J. and Bogdonoff, S. M., "Detailed Study of Attached and Separated Compression Corner Flowfields in High Reynolds Number Supersonic Flow," AIAA Journal, Vol. 17, No. 6, June 1979, pp. 579.

Settles, G. S., and Bogdonoff, S. M., "Experimental Study of Separated Flow and Turbulent Boundary Layers," Proceedings of the AFOSR Program Review on External Aerodynamics, Air Force Office of Scientific Research, Dayton, OH, June 1979.

Settles, G. S. and Perkins, J. J., "Investigation of Three Dimensional Shock/Boundary Layer Interactions at Swept Compression Corners," AIAA Paper 79 1498, July 1979.

Settles, G. S., Fitzpatrick, T. J. and Bogdonoff, S. M., "A Detailed Study of Attached and Separated Compression Corner Flowfields in High Reynolds Number Supersonic Flow," AIAA Paper 78 1167, July 1978.

Settles, G. S., Hamrick, J. T., Barr, W. J. and Summerfield, M., "The Definition of a National Program in Energy Efficient Pump Utilization," Final Report on Contract E(04 3) ¬1260 with the U. S. Energy Research and Development Administration, Princeton Combustion Laboratories, Princeton, NJ, April 1977.

Settles, G. S., Hamrick, J. T., Barr, W. J., Summerfield, M., and Gunn, M., "Energy Efficient Pump Utilization," AIAA Journal of Energy, Vol. 1, Jan. Feb. 1977, pp. 65 72.

Horstman, C. C., Settles, G. S., Vas, I. E., Bogdonoff S. M., Hung, C. M., "Reynolds Number Effects on Shock Wave Turbulent Boundary Layer Interactions A Comparison of Numerical and Experimental Results," AIAA Paper 77 42, Jan. 1977.

Settles, G. S., Vas, I. E. and Bogdonoff, S. M., "Details of a Shock Separated Turbulent Boundary Layer at a Compression Corner," AIAA Journal, Vol. 14, No. 12, December 1976, pp. 1709 1715.

Varney, A. M., Settles, G. S., Ingram, L. S. and Summerfield, M., "Quantitative Charac¬terization of the Ignition Behavior of NOS Monopropellants for Pre Loaded Liquid Propellant Gun Applications," Final Report on Contract N00174 76 C 0110 for U.S. Naval Ordnance Station, Indian Head, MD, Sept. 1976.

Settles, G. S., Bogdonoff, S. M., and Vas, I. E., "Incipient Separation of a Supersonic Turbulent Boundary Layer at High Reynolds Numbers," AIAA Journal, Vol. 14, No. 1, Jan. 1976, pp. 50 56.

Settles, G. S., Vas, I. E. and Bogdonoff, S. M., "Shock Wave Turbulent Boundary Layer Interaction at a High Reynolds Number, Including Separation and Flowfield Measurements," AIAA Paper 76 164, Jan. 1976.

Settles, G. S., et al., "An Exploratory Investigation of the Handling Sensitivity of Live Malfunctioned Stab Primers," Final Report on Contract N00174 75 C 0257 for the UI. S. Naval Explosive Ordnance Disposal Facility, Indian Head, MD, December 1975.

Settles, G. S., "An Experimental Study of Compressible Turbulent Boundary Layer Separation at High Reynolds Numbers," Ph.D. Dissertation, Aerospace and Mechanical Sciences Dept., Princeton University, Sept. 1975.

Settles, G. S., Bogdonoff, S. M. and Vas, I. E., "Incipient Separation of a Supersonic Turbulent Boundary Layer at Moderate to High Reynolds Numbers," AIAA Paper 75 7, Jan. 1975.

Settles, G. S. and Bogdonoff, S. M., "Separation of a Supersonic Turbulent Boundary Layer at Moderate to High Reynolds Numbers," AIAA Paper 73 666, July 1973.

Settles, G. S., "A Two Dimensional Color Schlieren Technique," Image Technology, June/July 1972, pp. 19 23.

Settles, G. S., "A Portable Supersonic Tunnel for $200.," Paper presented at the AIAA Northeast Student Conference, Rutgers University, New Brunswick, NJ, 1972.

Settles, G. S., "A New Quantitative Schlieren Technique for Use in Heat Transfer and Gas Dynamics," Paper presented at the ASME Region IV Student Conference, Durham, NC, April 1971.

Settles, G. S., "A Four Color Schlieren Techique with Sensitivity in All Directions," Tennessee Engineer, December 1970, pp. 4 9.

Settles, G. S., "A Direction Indicating Color Schlieren System," AIAA Journal, Vol. 8, No. 12, December 1970, pp. 2282 2284.